Essays in International Macroeconomics and Financial Crisis Forecasting

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Chapter 1

Introduction

This thesis contributes long-run perspectives to the research on international macroeconomics and macro-finance. Chapters 2 and 3, analyze international financial linkages and their evolution over the past 150 years. Chapter 4 analyzes external adjustment under the pre-1914 Gold Standard – a fixed exchange rate regime in many ways reminiscent of today's euro area. Finally, chapter 5 uses the accumulated financial crisis experience since 1870 to evaluate the financial crisis forecasting performance of modern machine learning algorithms.

Chapter 2, titled *"Global risk-taking, exchange rates and monetary policy"*, revisits one of the core ideas in international macroeconomics, the idea that floating exchange rates help to decouple local interest rates from foreign rates. I find that this is only the case for safe rates, but not for risky rates. For risky rates, I find that their co-movement has increased over the 20th century, regardless of exchange rate regime. Why have floating exchange rates become less effective in decoupling risky rates? I argue that the growing role of leverage-constrained banks in global asset markets is key. More specifically, I introduce an international banking model in which banks' leverage constraints induce excessive volatility into risky rates, and their arbitrage activity spreads this volatility internationally, thus overwhelming floating exchange rates, which are already pinned down by safe rates.

In chapter 3, which is joint work with Òscar Jordà, Alan M. Taylor and Moritz Schularick, we analyze the international co-movement of financial cycles and the effect of U.S. monetary policy on global asset prices. We show that the co-movement of financial variables has increased in the long run. The sharp increase in the co-movement of global equity markets in the past three decades is particularly notable. We demonstrate that fluctuations in risk premiums, and not risk-free rates and dividends, account for most of the observed equity price synchronization post-1980. We also show that U.S. monetary policy has come to play an important role as a source of fluctuations in risk appetite across global equity markets.

Chapter 4, titled "When do fixed exchange rates work? Evidence from the Gold Standard" explores the circumstances under which a fixed exchange rate regime works. In joint work with Yao Chen, we empirically and theoretically analyze one of the world's largest and most durable fixed exchange rate regimes, the Gold Standard. External adjustment under the Gold Standard was associated with few, if any, output costs. In this chapter, we evaluate how flexible prices, international migration, and monetary policy contributed to this benign adjustment experience. For this purpose, we build and estimate an open economy model for the Gold Standard (1880-1913). We find that the output resilience of Gold Standard members that underwent external adjustment was primarily a consequence of flexible prices. When hit by a shock, quickly adjusting prices induced import- and export responses that stabilized incomes. Crucial in this regard was a historical contingency: namely large primary sectors, whose flexibly priced products drove the export booms that stabilized output during major external adjustments.

Finally, chapter 5 contributes to the literature on financial crisis forecasting, using high dimensional data and modern machine learning algorithms. In this chapter, titled *"Spotting the danger zone: Forecasting financial crises with classification tree ensembles and many predictors"*, I introduce classification tree ensembles (CTEs) to the banking crisis forecasting literature. I show that CTEs substantially improve out-of-sample forecasting performance over best practice early-warning systems. CTEs enable policymakers to correctly forecast 80% of crises with a 20% probability of incorrectly forecasting a crisis. These findings are based on a long-run sample ($1870 - 2011$), and two broad post-1970 samples which together cover almost all known systemic banking crises. More particular, I show that the marked improvement in forecasting performance over conventional best practice models results from the combination of many classification trees into an ensemble, and the use of many predictors (i.e., > 100).

Chapter 2

Global risk-taking, exchange rates, and monetary policy

2.1. Introduction

In this paper, I revisit one of the central ideas in international macroeconomics, the idea that floating exchange rates decouple local interest rates from foreign rates. The effectiveness of floating exchange rates in decoupling local interest rates has been confirmed by empirical evidence based on *safe interest rates*, such as central bank policy rates or government bond yields (Obstfeld, Shambaugh and Taylor, 2005; Shambaugh, 2004). Recent research, however, has suggested that floating exchange rates can become overwhelmed by global financial forces that bind together *risky rates*, such as bank lending rates or corporate bond yields (Passari and Rey, 2015; Rey, 2016). On the basis of new long-run time series for safe *and* risky interest rates, I find that floating exchange rates have indeed become less effective at decoupling risky rates than safe rates. I introduce an open economy model that rationalizes this phenomenon with the growing role of leverage-constrained banks in global asset markets (see Adrian, Etula and Muir, 2014; Adrian, Moench and Shin, 2016).

In the empirical part of this paper I present two pieces of evidence for the decreasing effectiveness of floating exchange rates. First, in a co-movement analysis I show that, during the late 20th century, floating exchange rates reduced the co-movement of local safe rates with foreign safe rates by around 80%, while the corresponding figure for risky rates is considerably less, or statistically indistinguishable from 0, depending on which risky rate one looks at. I also show that this is a relatively new phenomenon. In the early 20th century, floating exchange rates were effective at decoupling risky rates.

Second, in order to compare the transmission of financial center monetary policy shocks to pegs and floats I look at the global effects of U.S. monetary policy shocks today and the global effects of U.K. monetary policy shocks in the early 20th century. For this purpose, I constructed a monetary policy shock measure for the Bank of England (BoE) from 1880 to 1913, and hand-collected an international dataset of monthly safe- and risky rates. On the basis of the new pre-1914 BoE shock measure, as well as the post-1970 Fed shock measure by Romer and Romer (2004), I compare the response of pegs and floats to financial center monetary policy shocks.[1] The results underscore the findings from the co-movement analysis: While floating exchange rates are effective at shielding local safe rates from financial center policy rate shocks, they are ineffective at shielding local risky rates. Again I can show that this is a recent phenomenon. Earlier in the 20th century floating exchange rates were still effective at decoupling risky rates from financial center policy rate shocks.

Why have floating exchange rates become less effective in decoupling risky rates? I argue that the growing role of leverage-constrained banks in global asset markets is key. More specifically I introduce an international banking model in which the interplay of leverage constraints, mark-to-market accounting, and costly equity adjustment gives rise to excess volatility in risky rates (see Adrian and Shin, 2009, 2010; Adrian, Etula and Muir, 2014; Adrian, Moench and Shin, 2016). In an open economy framework, this excess movement in risky rates overwhelms the floating exchange rate, which is already pinned down by the cross-country differential in safe rates.

To better understand the proposed mechanism consider a positive shock to the foreign safe rate. The nominal exchange rate adjusts to equalize expected safe returns across the two regions. At the same time foreign banks sell risky assets until their price has fallen sufficiently to compensate for the higher funding cost. The drop in risky asset prices furthermore erodes foreign and home bank equity. Subject to leverage constraints, and because raising new equity is costly, the banks will adjust their leverage by reducing their risk-taking even further. This sell-off of risky assets generates an excessive fall in risky asset prices (i.e., an excessive rise in risky rates). The nominal exchange rate cannot compensate for this excess rise in risky rates, because it is already pinned down by safe rates. Thus, the exchange rate ceases to function as an equalizer of expected returns for risky rates. Instead, risky returns are equalized across regions through risk premium spillovers, as banks arbitrage away expected return differentials between home and foreign risky assets. The calibrated model indicates that this *international risk-taking channel* can account for about 50% of the spillovers of U.S. monetary policy into the risky rates of floats.

The finding that floating exchange rates have become ineffective at decoupling local risky rates does not imply that floating exchange rates are not worth having. After all, a floating exchange rate provides economic policymakers with one more degree of freedom for achieving their policy goals. However, my findings suggest that the world economy has become a considerably more demanding environment to operate in for policymakers. Increasing financial spillovers can drive a wedge between conventional targets of monetary policy, such as output and employment gaps, and other policy goals, such as financial stability targets. This divergence in policy targets worsens the trade-offs involved in the application of existing policy instruments. Thus policymakers may find themselves in want of additional instruments in their policy toolkit.

My findings are also of relevance to current debates about how to robustify open economies

[1] I use the extended shock series provided by Cloyne and Hürtgen (2016)

against financial shocks from abroad (Rey, 2013; Passari and Rey, 2015). The finding that floating exchange rates were effective at decoupling risky rates in the early 20th century suggests that excessively volatile risk premiums and their international spillover is not an inevitable consequence of financial globalization. Hence, the implementation of capital controls – de facto financial deglobalization – is not the only way in which monetary authorities can reassert their control over local interest rates. Instead, my findings suggest that institutional reform, aimed at lightening the interaction between leverage-constraints and mark-to-market accounting, can help to reconcile capital mobility with monetary autonomy. In this regard, the institutions that underpinned financial globalization at the beginning of the 20th century are worth another look.[2]

This paper is closely related to several strands of literature. First, my work adds to the trilemma literature (Keynes, 1930; Fleming, 1962; Dornbusch, 1976; Padoa-Schioppa, 1982; Obstfeld and Taylor, 1997; Shambaugh, 2004; Obstfeld, Shambaugh and Taylor, 2005; Bluedorn and Bowdler, 2011; Klein and Shambaugh, 2015; Bekaert and Mehl, 2017; Obstfeld and Taylor, 2017; Obstfeld, Ostry and Qureshi, 2017).[3] The trilemma states that each economy can pursue only two out of the following three macroeconomic policies: mobile capital, stable exchange rates and independent interest rates. The empirical trilemma literature has tested whether capital controls and floating exchange rates are indeed associated with more independent interest rates. Most contributions have found that this is indeed the case. My findings confirm this as far as safe rates are concerned.[4]

Second, this paper contributes to a recent literature that has challenged the trilemma's validity. The so-called dilemma view put forward by Rey (2013) proposes that floating exchange rates no longer provide an effective insulation against global financial forces (see Miranda-Agrippino and Rey, 2015; Passari and Rey, 2015; Georgiadis and Mehl, 2015; Ha, 2016; Cerutti, Claessens and Rose, 2017). As a result, the trilemma has turned into a dilemma, according to which monetary autonomy can only be established through capital controls. In this paper I confirm that extensive risk premium spillovers have rendered floating exchange rates ineffective at shielding local risky rates. My findings thus reconcile the trilemma and dilemma views. While I find that the trilemma holds for safe rates, the dilemma holds for

[2] This is not to say that systematic window-dressing is a solution. However, the proposed model mechanism opens the door for frictions, that delay the translation of asset price volatility into balance sheet volatility, to play a stabilizing role.

[3] This literature in turn is closley related another empirical strand of interantional macroeconomics, that tests the validity of (un-)covered interest rate parity (UIP) (see Froot and Thaler, 1990; Bekaert, Wei and Xing, 2007; Lothian and Wu, 2011; Pikoulakis and Wisniewski, 2012; Stavrakeva and Tang, 2015)

[4] Obstfeld, Ostry and Qureshi (2017) present evidence that the transmission of global financial shocks is magnified under fixed exchange rate regimes. However, their findings indicate that the peg-float dichotomy is less marked when it comes to stock returns, debt and equity portfolio flows, as well as cross-border banking flows (also see Cerutti, Claessens and Puy, 2015). My findings confirm that the decoupling power of floating exchange rates depends on the type of financial variable. The proposed model furthermore suggests that the ease of arbitrage and the degree of leverage are crucial for understanding which financial variables can achieve decoupling through floating exchange rates.

risky rates.[5]

Finally, the open economy model I propose builds on closed economy models introduced by Danielsson, Shin and Zigrand (2012) and Adrian and Boyarchenko (2013*b*), which study the macroeconomic implications of value-at-risk (VaR) constrained banks. More generally, this paper adds to the theoretical literature that analyzes the role of financial frictions in the international transmission of shocks (Kollmann, Enders and Müller, 2011; Ueda, 2012; Kalemli-Ozcan, Papaioannou and Perri, 2013; Alpanda and Aysun, 2014). Among these, the model I propose is most closely related to accounts that highlight the role of asset prices in synchronizing financial conditions across borders (Fostel and Geanakoplos, 2008; Devereux and Yetman, 2010; Dedola and Lombardo, 2012).

The remainder of this paper is structured as follows: In the empirical part, sections 2.2.1 and 2.2.2 outline the econometric strategies I employ. Sections 2.2.1 and 2.2.2 introduce the annual and monthly interest rate datasets. Sections 2.2.1 and 2.2.2 present the empirical results. The international risk-taking channel is outlined in section 2.3. To quantitatively evaluate this channel I introduce, discuss and calibrate an open economy banking model in sections 2.4.1, 2.4.3 and 2.4.3. Finally, in section 2.4.4 I confront the model with the empirical results and assess to which extent the model accounts for the observed co-movement in risky rates among floats. Section 2.5 concludes.

2.2. Empirical analysis of exchange rate regimes and interest rates

This first part of this paper empirically characterizes the relation between exchange rate regime and interest rate co-movement in two ways. In order to connect to the existing literature on interest rate co-movement I start with a regression-based co-movement analysis that checks whether interest rates co-moved differently among pegs and floats. After that, this section presents a conditional analysis of the transmission of financial center monetary policy shocks to pegs and floats.

2.2.1. Interest rate co-movement analysis

Methodological approach

In order to see how globally synchronized risk premiums can render floating exchange rates ineffective compare the uncovered interest rate parity (UIP) equation with its risk premium augmented equivalent. In the basic UIP equation

$$i_{k,t} = i_{l,t} + \mathbb{E}_t e_{kl,t+1} - e_{kl,t}, \tag{2.1}$$

[5] This strand of the literature is also closely related to another strand that analyzes the financial spillovers that emanate from financial centers (see Kim, 2001; Canova, 2005; Miniane and Rogers, 2007; Ehrmann and Fratzscher, 2009; Bruno and Shin, 2015). Relatedly, Forbes and Warnock (2012), Fratzscher (2012), Cerutti, Claessens and Puy (2015) and Ha and So (2017) present empirical evidence that global factors are important for understanding capital flows.

the co-movement of country k's nominal safe rate ($i_{k,t}$) with country l's ($i_{l,t}$) depends only upon the expected changes in the nominal exchange rate ($\mathbb{E}_t e_{kl,t+1} - e_{kl,t}$). For fixed exchange rates $\mathbb{E}_t e_{kl,t+1} - e_{kl,t} = 0$, and absent any frictions in international capital markets, arbitrage ensures that $i_{k,t}$ equals $i_{l,t}$, and hence safe rates co-move perfectly, i.e. $corr(i_{k,t}, i_{l,t}) = 1$. Floating exchange rates break this link: Given any home and foreign interest rate, $i_{k,t}$ and $i_{l,t}$, the expected change in the nominal exchange rate ($\mathbb{E}_t e_{kl,t+1} - e_{kl,t}$) adjusts until the non-arbitrage condition in (2.1) is satisfied.

In the risk premium augmented UIP equation

$$r_{k,t} = i_{l,t} + \rho_{l,t} + \mathbb{E}_t e_{kl,t+1} - e_{kl,t} \tag{2.2}$$

the co-movement of risky interest rates $r_{k,t} = i_{k,t} + \rho_{k,t}$ no longer only depends on the expected depreciation of the exchange rate, but also on the co-movement of the risk-premiums, $cov(\rho_{k,t}, \rho_{l,t})$.[6] Here I use the term "risk premium" to refer to any spread between safe and risky asset returns, regardless of whether it is related to fundamental default risk or not. For example, I also use the term "risk premium" to refer to interest rate spreads that open up due to limits of arbitrage.

The dilemma hypothesis as proposed by Rey (2013) posits that the ebb and flow in risk appetite is highly correlated internationally, i.e. $cov(\rho_{k,t}, \rho_{l,t}) >> 0$. In this scenario, even if two economies have a floating exchange rate and their fundamentals are otherwise unrelated, their risky rates will nevertheless co-move, i.e. $cov(r_{k,t}, r_{l,t}) > 0$. It is in this sense that a floating exchange rate has become a less powerful tool in decoupling an economy from international capital markets.

Nominal interest rates are known to be highly persistent and are thus often treated as unit root processes (see Shambaugh, 2004), that are potentially affected by problems of spurious correlation (Granger and Newbold, 1974; Phillips, 1986).[7] This also holds for the five interest rates I am studying here, for which the unit root test by Elliott, Rothenberg and Stock (1996) rejects the unit root hypothesis in only 10%, 5%, 9.5%, 4% and 2% of the spells for the short-term safe rate, the long-term risk free rate, mortgage rates, bank lending rate and private bond yield respectively.[8] In the following analysis I treat all interest rate series as near-unit root processes, whose asymptotic properties are more similar to the asymptotic properties of non-stationary processes than stationary ones (Phillips, 1988). In line with the existing literature I therefore base my analysis on the first differenced interest rate series in order to

[6] Equations 2.1 and 2.2 can be derived as the linear Taylor approximations for the first order conditions of a risk neutral investor that can choose between investing in a safe or a risky asset. In this case r, ρ and e are log-deviations from steady state.

[7] Nominal interest rates are no unit root processes strictly speaking as they are bounded from below by zero. Furthermore Stanton (1997) observes that while nominal interest rates are indistinguishable from a unit root process at low and medium interest rate levels, mean reversion is stronger when interest rate levels are very high or very low.

[8] I determined the lag length for the unit root test regressions according to modified AIC (Ng and Perron, 2001).

ensure correct results. After first differencing, equation 2.2 becomes

$$\Delta r_{k,t} = \Delta i_{l,t} + \Delta \rho_{l,t} + \Delta \left[\mathbb{E}_t e_{kl,t+1} - e_{kl,t} \right], \tag{2.3}$$

where Δ denotes the first difference-operator. For credible pegs the exchange rate is fixed, $\mathbb{E}_t(e_{kl,t+1}) = e_{kl,t}$, and thus equation 2.3 could be brought to the data as

$$\Delta r_{k,t} = \beta_1 \Delta i_{l,t} + \beta_2 \Delta \rho_{l,t} + u_{kl,t}, \tag{2.4}$$

where u indicates the error term. First differencing also nets out time-invariant country-specific level-characteristics in interest rates and risk premiums. These include interest rate-level differences due to differences in capital stock accumulation and overall economic development, as well as persistent institutional and political differences that are associated with persistent differences in risk premium levels.

Among two countries k and l with an absolutely fixed exchange rate and an integrated financial market for safe bonds the expected coefficient estimate for β_1 would be 1. Historically, most fixed exchange rate regimes allowed for some fluctuations of the nominal exchange rate within a narrow target zone. Cases of absolutely fixed exchange rates are rare and restricted to currency unions, such as the euro area, or fully dollarized economies, such as Panama. For this reason the following analysis defines a peg as a country whose exchange rate stays within a narrow a $+/-2\%$ horizontal band. Obstfeld, Shambaugh and Taylor (2005) present simulation evidence that in such target zone regimes UIP coefficient estimates should be expected to be substantially smaller than 1, around 0.5 and even smaller if central banks conduct an aggressive interest rate smoothing policy within their target zone band. In practice the presence of various kinds of arbitrage costs can be expected to drive another wedge between domestic and global rates, further lowering $\widehat{\beta}_1$ and $\widehat{\beta}_2$ (hatted parameters denote parameter estimates). Generally, however, $\widehat{\beta}_1$ should be expected to be positive and significantly larger than 0 among pegs.

The sign and size of $\widehat{\beta}_2$ depends on the extent of financial market integration for risky as well as safe assets. When the markets for both, safe and risky assets, are perfectly integrated $\widehat{\beta}_2$ should equal 1, i.e. risk premiums are equalized across borders (see Dedola and Lombardo, 2012). If either the market for safe or risky assets are not perfectly integrated there is some scope for ρ_k and ρ_l to deviate from one another. Practically $\widehat{\beta}_2$ might deviate from 1 not only due to frictions in international asset markets, but also due to imperfect cross-country comparability of the risk rate series. In general, however, among financially open economies and when comparing assets of the same risk-class across countries $\widehat{\beta}_2$ should be expected to be positive – particularly so for the case of extensive risk premium spillovers posited by the dilemma hypothesis.

For economies with a floating exchange rate, uncovered interest rate parity can be satisfied through movements in either the expected exchange rate $\mathbb{E}_t e_{kl,t+1}$ or the spot exchange rate $e_{kl,t}$ instead of movements in the safe rate or the risk premium. Consequently, estimates of β_1 among floats should be expected to lie below that among pegs. Various factors however suggest that $\widehat{\beta}_1$ will not equal 0. First, the lack of the expected change in the exchange rate in specification 2.4 constitutes an omitted variable problem.[9] Second, shocks might be correlated across countries provoking synchronized central bank responses even among floats. Finally, even central banks that do not directly target the exchange rate respond to foreign interest rate shocks to the extent that any of their targets, be it inflation or output gaps, gets affected by it. Despite these caveats it will be informative to take a look at the regression results, also in order to get an idea of how the results presented here relate to results reported by key reference papers that have applied similar UIP regressions (Shambaugh, 2004; Obstfeld, Shambaugh and Taylor, 2005). In order to sharpen the peg-float contrast, I will exclude countries that follow an intermediate exchange rate regime, such as a managed float or a crawling peg from the following analysis (see Klein and Shambaugh, 2015).

In the following I will make use of a regression equation that allows to directly compare interest rate co-movement among pegs and floats, and that allows to statistically test whether floating exchange rates have the power to decouple domestic interest rates:

$$\Delta r_{k,t} = \beta_0 + \beta_1 \Delta r_{l,t} + \beta_2 \Delta r_{l,t} * float_{kl,t} + u_{kl,t} \,, \tag{2.5}$$

where $float$ denotes a float dummy taking the value 1 for free floats and 0 for strict pegs. r the risky rate, and u is the error term. In this specification β_1 indicates the strength of the co-movement of domestic risky rates with foreign risky rates among pegs and β_2 indicates the efficacy of a floating exchange rate in decoupling the domestic risky rate from their foreign counterpart. On the basis of this specification it is possible to give an indication of the *decoupling power* of a floating exchange rate:

$$DCP = \frac{\widehat{\beta}_2}{\widehat{\beta}_1} \,. \tag{2.6}$$

The ratio quantifies the effectiveness of a floating exchange rate in decoupling local interest rates from foreign ones. A value of -1 indicates that a floating exchange rate has the power to

[9] In this case the use of ex post realized exchange rates as proxies for their ex ante expected counterparts has proven of little help in alleviating this omitted variable problem. Several papers in the literature have shown that in the case of floating exchange rates the uncovered interest parity equation does not hold when proxying ex ante exchange rate expectations with ex post realized exchange rates (e.g. Froot and Thaler, 1990). A recent exception are Lothian and Wu (2011), who, using ex post realized exchange rates as a proxy for expected exchange rates, find UIP to hold on their 200-year sample for U.K, U.S. and French returns. The bias this omitted variable problem induces in β_1 could be positive or negative depending on economic circumstances. Foreign interest rate changes could be positively correlated with the expected depreciation term if there is an economic crisis with capital outflows that the central bank tries to rein in through higher policy rates. Such scenarios would result in an overestimate of the systematic co-movement in interest rates among floats. The same holds for the mirror image of this scenario, i.e. a safe haven where capital inflows put upward pressure on the exchange rate, but who at the same time lowers its policy rates. A downward bias in β_1 would follow from scenarios in which lower policy rates and an expected exchange rate depreciation are the result of an anticipated period of sluggish economic growth. In general, however, there is no reason to believe that among floats β_1 would be systematically overestimated due to this omitted variable problem, and hence among floats β_1 can be expected to be lower than among pegs if UIP holds.

completely uncouple domestic rates from foreign ones. A value of 0 indicates that floating exchange rates are completely ineffective. The analogous measure can be calculated for safe rates.

Finally, the above argument assumes an open capital account. If effective capital controls are in place this constitutes another way domestic interest rates can diverge from the base country's rate. In order to sharpen the focus on the peg-float dichotomy the following analysis focuses on open pegs and open floats only, excluding bilateral country-pair-year observations in which any of the two countries in the pair has capital controls in place.

Data

In this section I introduce the dataset and discuss the important issue of exchange rate regime classification. The core of the dataset comprises annual interest rate data from the latest vintage of the Jordà-Schularick-Taylor (JST) Macrohistory Database (Jordà, Schularick and Taylor, 2016, `http://www.macrohistory.net/data/`). This database ranges from 1870 to 2015 and covers 17 countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, U.K. and the U.S.. Combined, these 17 countries make up more than 30% of world GDP throughout the sample period. For the post-1950 period I extended this sample by an additional 156 countries for which interest rate data was available from public sources, either the IMF's International Financial Statistics, national statistical offices or national central banks (see table 2.16).

Interest rates: To compare the co-movement of short-term risk free rates with risky rates I make use of the short-term safe rate contained in the JST database. Concerning risky rates, there exist various candidate rates. Risk premiums differ according to the riskiness of the underlying investment projects. Lending secured by mortgages may carry a lower premium than bank lending to businesses. Furthermore, the institutional framework within which intermediation takes place matters for the riskiness of an investment. Most notable here is the distinction between bank lending and capital market based lending. For this reason the following analysis will also look at corporate bond yields. Long-run series from 1870 to 2015 on these risky rates have recently been compiled for the above listed 17 country sample by Zimmermann (2017) (mortgage- and bank lending rates) and Kuvshinov (2017) (corporate bond yields). The broader post-1950 sample draws from various public sources.[10]

Maturity also matters. While short-term safe rates range from overnight rates (interbank lending) to 3-month rates (treasury bills) the maturity of the average corporate bond underlying the corporate bond yield series centers around 10 years.[11] In order not to confound risk

[10] Data availability differs widely across series. Only few countries host liquid corporate bond markets. Coverage for the private bond yield series is thus generally lower than that for the mortgage rate- or bank lending rate series.

[11] The average maturity of the mortgage contracts underlying the mortgage rate series are also at the longer end of the maturity range, whereas the bank lending series reflects the price of risky intermediation at shorter maturities.

premiums effects with term premiums effects the following analysis corrects for the term premium. This term premium is calculated as the difference between short-term safe rates and long-term safe rates. For the long-run 17-country sample the long-run government bond yield series I use also comes from Kuvshinov (2017), while for the additional 156 countries in the post-1950 sample I again draw from the IMF's International Financial Statistics, national statistical offices and national central banks.

Due to its scope the sample contains various extreme episodes, outliers that if not dropped would dominate any non-robust estimation procedure. I thus drop any country-pair-year observation in which the first difference of the domestic or base country interest rate exceeds 50 ppts. This excludes the most severe cases of hyperinflation and financial panic from the analysis.

Finally I followed Obstfeld, Shambaugh and Taylor (2005) in making the following sample adjustments: I dropped country-pair-year observations in which one of the countries changes its exchange rate status from peg to float or vice versa. I deleted the war years 1914-1918 and 1939-1945, and in order to remove administered non-market rates from the sample I dropped spells during which interest rates stay constant for more than 2 years.

Exchange rate regime: The classification of the exchange rate regime has long been recognized as an important issue in the empirical trilemma literature (Klein and Shambaugh, 2015). Before World War 2 my peg dummy follows Obstfeld, Shambaugh and Taylor (2004) and Obstfeld, Shambaugh and Taylor (2005); thereafter I rely on the exchange rate regime classification scheme of Ilzetzki, Reinhart and Rogoff (2008) (1940-1959) and the Shambaugh exchange rate classification dataset (1960-2014) (Shambaugh, 2004; Klein and Shambaugh, 2008; Obstfeld, Shambaugh and Taylor, 2010).[12] Thus my peg dummy takes the value of 1 if a country was on the gold standard before 1940. From 1940 on it is 1 for economies, whose exchange rate stays within a $+/-2\%$ band, and 0 otherwise.[13] The distinction between pegs and floats becomes less clear-cut over time, because the trilemma gets "cornered" more often by intermediate regimes, such as crawling pegs and managed floats (Klein and Shambaugh, 2015). In order to focus on the peg-float distinction I abstract from such intermediate regimes and focus on strict pegs and free floats only, strict pegs being defined as countries whose exchange rate remains within a $+/-2\%$ horizontal band.

With respect to the selection of the base country against which other countries peg, I for the most part follow Jordà, Schularick and Taylor (2015) and Shaumbaugh's exchange rate regime classification dataset. With only a few exceptions in the 17-country pre-1914 sample, the U.K. is usually treated as the base country. For the Netherlands, Norway, Italy and the U.K. itself, however, Germany is considered the base country (see Morys, 2010, on the details of

[12] I switch from the Ilzetzki, Reinhart and Rogoff (2008) to the Shambaugh (2004) exchange rate classification scheme at the earliest possible date in order to make my results more comparable to the latter, whose findings constitute a key reference for my analyisis.

[13] I follow Obstfeld, Shambaugh and Taylor (2005) in not considering one-off re-alignements as breaks in the peg regime. Similarly, single-year pegs are recoded as floats, as they quite likely simply reflect a lack of variation in the exchange rate.

who followed who during the pre-1914 Gold Standard). In the interwar period exchange rate relations become more complex. With a few exceptions the following holds for the 17 country interwar sample: The U.S. is the base until its devaluation in 1933. Thereafter France takes over as base from 1933 to 1935. From 1936 onwards, with France's exit from gold, the U.S. becomes the general base again.[14] Exceptions to this general pattern are the following cases (see Eichengreen and Irwin, 2010): Two countries, Canada and Italy follow the U.S. after its exit from gold. Thus the U.S. remains their base throughout the interwar years. The sterling bloc, consisting of Australia, Norway, Denmark, Finland, Sweden and Japan leave the Gold Standard in 1931 shortly after the U.K., which thus remains their base country until 1939.[15] After 1945, and up to 1959 in general the U.S. continues to be the base for the 17 country sample. The only exception to this is Australia which remains part of the Sterling bloc. Furthermore Germany is treated as the U.S.'s base country. From 1960 on I for the most part rely on the base country classification from the Shambaugh exchange rate classification dataset.[16]

The peg dummy together with the base country indicator allows me to construct a bilateral dataset and a bilateral peg dummy which reflects the exchange rate regime prevailing between any country-pair at any point in time. Thus in years when Italy was pegged against Germany, and Germany against the U.S. also Italy and the U.S. are treated as a fixed exchange rate pair. Similarly in years when both, Canada and Japan, are pegged against the USD Canada and Japan are also treated as a fixed exchange rate pair. I construct the bilateral peg dummy that indicates whether the exchange rate between any two countries k and l is fixed or floating in three steps.

First, on the basis of the peg dummy and the base country series it is possible to determine country-pairs that entertain an indirect peg status. Historically, there exist hardly any cases of more indirect pegs than those of second order, meaning that two countries' exchange rates are linked to one another indirectly through a chain of pegs involving two other countries (see the above example on Italy and the U.S.). Figure 2.1 gives a schematic description of all possible indirect bilateral peg relations.

Second, I separate the country-pairs with indeterminate bilateral exchange rate status from the bilateral floats. If there were no missing values with respect to the peg status and the base country for any observations, the set of bilateral floats would simply be the complement of the bilateral peg set. However, there are several missing values for the peg and base country variables. Thus in many years it is impossible to determine whether a country-pair entertains an indirect peg. In this case I set the bilateral peg dummy to missing, with one exception: It is possible to determine that two countries' exchange rate is floating regardless of whether information on the respective base countries is missing if the peg dummy equals zero for both

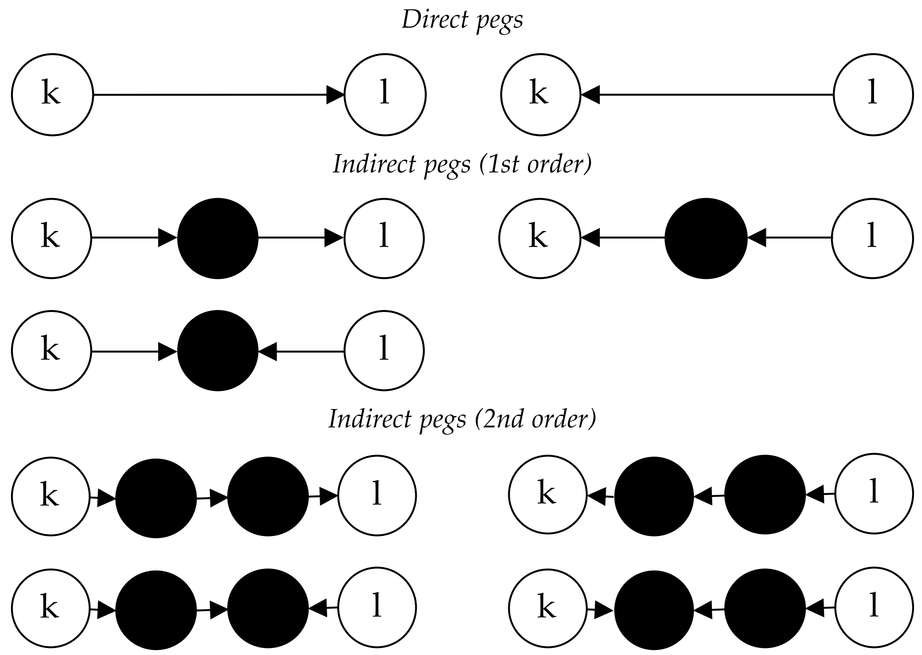
[14] In 1932, between the U.K. exit and the U.S. exit from gold France is treated as the base for the U.S..

[15] Here I deviate from the base classification by Jordà, Schularick and Taylor (2015), who define a hybrid base interest rate as the average of French, U.K. and U.S. rates. The reported results however are robust to the base rate definition in Jordà, Schularick and Taylor (2015).

[16] One exception is Australia, which up to 1966 is pegged to the British pound (GBP), at which point the U.K. devalues but the Australian dollar does not follow.

countries.

Figure 2.1: *Bilateral pegs*



Notes: Circles indicate countries. Arrows indicate peg relations, with the arrow head pointed towards the base country.

Finally, once the set of bilateral pegs and indeterminate cases have been identified the set of bilateral floats is the remaining complement. This approach allows me to exploit the many indirect pegs and floats contained in the sample. This approach drastically increases the number of bilateral country-pair observations over the more conventional approach of only considering country-pairs in which at least one of the countries is a canonical base country (either the U.S., the U.K. or Germany) (Shambaugh, 2004; Obstfeld, Shambaugh and Taylor, 2005).

Capital controls: Capital controls are an important conditioning variable when testing the effectiveness of floating exchange rates in decoupling local interest rates. For the post-Bretton Woods period I use the latest vintage of the openness indicator by Chinn and Ito (2008) in order to separate open economies from ones with significant capital controls in place.[17] The openness indicator by Chinn and Ito (2008) exhibits a trimodal distribution (see Klein and Shambaugh, 2015) of open economies, closed economies, and a middle group of countries with some capital controls, but fewer and less stringent ones than the closed economy group. I construct a capital control dummy that treats only observations with an openness indicator above or equal to .79 (separating the highest mode) as open economies and all others as

[17] In some cases I fill missing values for the post-1973 data by gleaning at the openness indicator provided by Quinn, Schindler and Toyoda (2011).

closed.[18]

During the Bretton Woods era most countries had implemented capital controls of one kind or another. The few exceptions, such as Canada between 1952 and 1967 or Germany between 1957 and 1972 are documented in the dataset by Quinn, Schindler and Toyoda (2011) or by Beckers (2006). For the interwar years I rely on the capital control data from the League of Nations that has been compiled by Obstfeld, Shambaugh and Taylor (2004), the capital account openness information contained in Eichengreen and Irwin (2010) and again the openness indicator by Quinn, Schindler and Toyoda (2011). Finally for the pre-1914 years I follow Obstfeld, Shambaugh and Taylor (2005) with respect to the capital control dummy in that I treat capital controls as alien to that period.

Results

In order to empirically assess the extent to which international co-movement in risk premiums has compromised the effectiveness of floating exchange rates I will first study the degree of co-movement of risk-premiums. After having established that risk premiums co-move globally, this section provides a quantitative assessment of the degree to which floating exchange rates have been overwhelmed by global co-movement in risk premiums.

The global co-movement of risk premiums: To analyze the co-movement of risk premiums I run regressions of the form

$$\Delta\rho_{k,t} = \beta_0 + \beta_1\Delta\rho_{l,t} + \epsilon_{kl,t}, \tag{2.7}$$

where $\rho_{k,t}$ and $\rho_{l,t}$ denote the risk premiums in countries k and l respectively. The risk premium in mortgage rates and private bond yields is calculated as the difference between the risky rate and the long-term safe rate, whereas the bank lending risk premium is calculated as the difference between the bank lending rate and the short-term safe rate, due to the generally shorter maturity of the underlying bank loans. I furthermore compare the co-movement in risk premiums with the co-movement of safe rates.

The results displayed in table 2.1 indicate that there is significant co-movement in international risk premiums. Co-movement is strongest for the risk premiums calculated from mortgage rates and private bond yields. As a robustness check, figure 2.9 in the appendix shows the equivalent results obtained from risk-premiums that I have calculated by subtracting base-country safe rates instead of local safe rates from local risky rates (i.e. U.S., U.K., and Germany safe rates). For these risk premiums the co-movement is even closer.

Floats at risk? The previous paragraph has shown that risk premiums co-move internationally. To which extent does this practically invalidate the trilemma for risky rates? To address

[18] An important reason for this rather strict separation of economies with an open capital account from economies with partly regulated capital accounts is that for the international equalization of risk premiums for assets within the same risk class to occur capital markets for safe as well as risky assets have to be integrated (see Dedola and Lombardo, 2012).

Table 2.1: *International co-movement of safe rates and risk premiums*

	Safe rates		*Risk premia*		
	Δi^{ST}	Δi^{LT}	$\Delta\rho^{\text{Mort}}$	$\Delta\rho^{\text{Bank}}$	$\Delta\rho^{\text{Corp}}$
β_1	0.013**	0.038**	0.056**	0.013***	0.150**
	(0.006)	(0.017)	(0.027)	(0.005)	(0.073)
N	271204	15252	4874	7903	1449
R^2	0.04	0.23	0.29	0.17	0.10

Notes: Estimated β_1 coefficients from regression equation 2.7. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Pre-1914 (1874-1913), Interwar (1925-1938), Bretton Woods (1950-1969), Post-Bretton Woods (1974-2015). Sample excludes WW1 (1914-1918) and WW2 (1939-1945) periods, as well as outliers, defined as absolute interest rate movements in excess of 50 ppts.

this question I estimate regression equation 2.5 and show the decoupling power of floating exchange rates (equation 2.6). The analogous measure for safe rates is obtained by substituting the risky rate r in equation 2.5 with a safe rate i and using the resulting coefficient estimates to form the DCP ratio.[19]

The coefficient estimates and the ratio are displayed in table 2.2. Clearly, among pegs there exists strong and significant co-movement of domestic interest rates with foreign safe- and risky rates. The estimated coefficients on the float-interaction term suggest that a floating exchange rate is effective at decoupling local safe rates. For them, a floating exchange rate achieves an -87% to -96% reduction in co-movement; similarly so for mortgage rates. With respect to the more risky bank lending rate and corporate bond yields the estimated coefficients suggest that floating exchange rates are ineffective, with insignificant DCPs of -19% and an insignificant 11% respectively. The evidence thus supports the thesis that a floating exchange rate is less useful in achieving domestic monetary autonomy when it comes to risky rates than for safe rates.

The emergence of a global risk premium co-movement: Is strong international co-movement in risk premiums a new phenomenon or have risk premium spillovers always overcome flexible exchange rates? In order to answer this question I look at the co-movement of risk premiums in four sub-samples: The pre-1914 Gold Standard era, the interwar years, the Bretton Woods era and the post-Bretton Boods period. The interwar subsample excludes the years 1919 - 1924 and 1931 - 1935, the chaotic construction- and collapse-years of the interwar Gold Standard. The Bretton Woods subsample starts in 1950 and lasts until 1969, the beginning of a phase of speculative attacks that ushers in the end of the Bretton Woods era.

The subsample results are displayed in table 2.3. Safe short-term and long-term rates have exhibited significant international co-movement throughout the past 150 years. Unsurprisingly co-movement among safe rates was stronger in earlier sub-periods – the pre-1914 Gold

[19]In order to avoid giving excessive weight to Eurozone interest rates I only considered German interest rates and dropped other Eurozone members' rates from the analysis.

Table 2.2: *The decoupling power of floating exchange rates*

	Safe rates		*Risky rates*		
	Δi^{ST}	Δi^{LT}	Δr^{Mort}	Δr^{Bank}	Δr^{Corp}
β_1	0.10**	0.59***	0.27***	0.38***	0.47***
	(0.05)	(0.04)	(0.07)	(0.07)	(0.11)
β_2 $(float)$	-0.09*	-0.57***	-0.21***	-0.07	0.05
	(0.05)	(0.05)	(0.07)	(0.08)	(0.11)
DCP	-87%	-96%	-79%	-19%	11%
	(7.92)	(3.15)	(15.20)	(18.55)	(25.87)
N	17344	5854	4018	2451	1067
R^2	0.35	0.31	0.35	0.29	0.40

Notes: DCP – decoupling power of floating exchange rates. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Pre-1914 (1874-1913), Interwar (1919-1938), Bretton Woods (1950-1972), Post-Bretton Woods (1973-2007). Sample excludes WW1 (1914-1918) and WW2 (1939-1945) periods, as well as outliers, defined as absolute interest rate movements in excess of 50 ppts. Standard errors in parentheses.

Table 2.3: *The rise of risk premium co-movement*

	Safe rates		*Risk premia*		
	Δi^{ST}	Δi^{LT}	$\Delta \rho^{\text{Mort}}$	$\Delta \rho^{\text{Bank}}$	$\Delta \rho^{\text{Corp}}$
			Pre-1914		
β_1	0.13***	0.17***	0.01	0.02	0.01
	(0.01)	(0.02)	(0.02)	(0.03)	(0.04)
N	3032	2542	1113	169	596
R^2	0.05	0.09	0.07	0.06	0.03
			Interwar		
β_1	0.25***	0.05	0.10	0.13**	-0.01
	(0.03)	(0.06)	(0.07)	(0.06)	(0.07)
N	686	609	382	190	278
R^2	0.24	0.10	0.08	0.43	0.22
			Bretton Woods		
β_1	0.05***	0.20***	-0.01	0.05	0.05
	(0.01)	(0.02)	(0.03)	(0.04)	(0.04)
N	6017	3328	943	805	739
R^2	0.24	0.09	0.06	0.10	0.02
			Post-Bretton Woods		
β_1	0.02***	0.03***	0.06***	0.03***	0.13***
	(0.00)	(0.00)	(0.01)	(0.01)	(0.04)
N	249943	33751	5498	13609	1246
R^2	0.04	0.11	0.15	0.06	0.02

Notes: Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Pre-1914 (1874-1913), Interwar (1919-1938), Bretton Woods (1950-1972), Post-Bretton Woods (1973-2007). Sample excludes WW1 (1914-1918) and WW2 (1939-1945) as well as outliers, defined as absolute interest rate movements in excess of 50 ppts.

Standard, the Gold Exchange Standard of the interwar years and the Bretton Woods system – all gold-based fixed exchange rate regimes. In contrast, extensive international co-movement of risk premiums is a rather new phenomenon that is unique to the post-1973 period. Only for the interwar years is there some indication of international risk premium co-movement as evidenced by the significant coefficient for the bank-lending risk premium.[20]

The declining effectiveness of floating exchange rates: To get an idea of what the emergence of global co-movement in risk premiums means for the decoupling power of floating exchange rates over time this section presents a sub-period analysis of regression equation 2.5 and the decoupling power (DCP) ratio (equation 2.6). I consider the same four subsamples introduced earlier. Table 2.4 shows the results.

The pre-1914 era stands out as an era in which floating exchange rates had strong decoupling power. DCPs for the most part indicate that the co-movement from pegging the exchange rate is completely compensated for by floating.[21] The decoupling power in the interwar years is similarly strong. Note, however, that the coefficients for corporate bond yields reverse sign. During the Bretton Woods era DCPs among bank lending rates and corporate bond yields are low, while DCPs for safe rates and mortgage lending rates remain high. In the immediate post-WW2 decades financial regulation, capital controls and the sheer absence of some financial markets broke the link between domestic and foreign risky rates.[22] Finally, in the post-Bretton Woods era, the overall degree of independence afforded by floating exchange rates has reached its lowest point in the past 150 years. Among bank lending rates and corporate bond yields floating exchange rates' decoupling power ranges from -59% to a statistically insignificant -26%.

The appendix presents the results of various additional analyses, which check the robustness of the findings presented here. Removing countries of dubious data quality from the sample yields very similar results (table 2.10). Among advanced economies floating exchange rates are somewhat less effective at decoupling risky rates (table 2.11) than among emerging markets (table 2.12).[23] With an eye on sample comparability over time, table 2.13 considers only the 17 early developing economies that are part of the pre-1914 sample for the post-1973

[20]For the subsample regressions I dispense with capital control regressors. The temporal dimension acts as a control for the degree of financial integration (see Obstfeld, Shambaugh and Taylor, 2005). Capital controls were low or non-existent prior to 1914, they were then built up during World War I and subsequently rolled back until the international monetary system broke apart during the Great Depression. The Bretton Woods era was characterized by strict capital controls, which then again were rolled back after the Bretton Woods regime came to an end.

[21]A DCP statistic below -100% points towards negative interest rate co-movement among floats.

[22]The Bretton Woods subsample is relatively short. The empirical UIP literature has long recognized that short samples are prone to yield paradoxical parameter estimates due to periods of imperfect expectation formation. For example, during the 1980s disinflation inflation expectations remained stubbornly high for a prolonged period. Such ex post expectation errors are more likely to dominate parameter estimates on short samples than on long ones (Lothian and Wu, 2011).

[23]This conforms with recent findings by Obstfeld, Ostry and Qureshi (2017) who show that, for a sample of emerging market economies, a floating exchange rate is still associated with more economic independence.

Table 2.4: *Effectiveness of floating for decoupling from global interest rates, all coefficients*

	Safe rates		*Risky rates*		
	Δi^{ST}	Δi^{LT}	Δr^{Mort}	Δr^{Bank}	Δr^{Corp}
			Pre-1914		
β_1	0.19***	0.42***	0.10***	0.33***	0.31***
β_2 $(float)$	-0.13***	-0.40***	-0.10	-0.27**	-0.41***
DCP	**-71%**	**-95%**	**-96%**	**-82%**	**-133%**
	(11.65)	(7.66)	(54.35)	(16.87)	(31.37)
N	3032	2542	1382	210	596
R^2	0.07	0.13	0.10	0.18	0.08
			Interwar		
β_1	0.38***	0.23	0.26**	0.79***	-0.13**
β_2 $(float)$	-0.38***	-0.26	-0.20*	-0.77***	0.11*
DCP	**-99%**	**-109%**	**-77%**	**-97%**	**-88%**
	(8.37)	(23.89)	(18.51)	(6.04)	(25.90)
N	686	609	519	216	278
R^2	0.28	0.11	0.10	0.33	0.06
			Bretton Woods		
β_1	0.14***	0.26***	0.16***	0.26***	0.31***
β_2 $(float)$	-0.16***	-0.16	-0.15***	0.02	0.15
DCP	**-115%**	**-63%**	**-94%**	**8%**	**48%**
	(46.02)	(35.91)	(38.27)	(24.17)	(37.71)
N	4907	2455	1110	771	518
R^2	0.32	0.12	0.17	0.18	0.18
			Post-Bretton Woods		
β_1	0.08***	0.14***	0.15**	0.23***	0.62***
β_2 $(float)$	-0.06***	-0.11**	-0.11*	-0.12***	-0.13
DCP	**-76%**	**-81%**	**-76%**	**-50%**	**-20%**
	(10.23)	(9.48)	(13.13)	(10.96)	(19.14)
N	165930	21100	10498	8912	674
R^2	0.07	0.19	0.16	0.13	0.30

Notes: *DCP* – decoupling power. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Pre-1914 (1874-1913), Interwar (1919-1938), Bretton Woods (1950-1972), Post-Bretton Woods (1973-2007). Sample excludes WW1 (1914-1918) and WW2 (1939-1945) periods, as well as outliers, defined as absolute interest rate movements in excess of 50 ppts. R^2 and the number of observations N refer to the underlying regressions from which the parameters for the calculation of the decoupling power DCP have been obtained.

sample. Again, floating exchange rates exhibit decoupling power for safe rates, but not for risky ones. Finally, instead of considering 1-year changes in interest rates I also looked at 2-year changes. Some findings in the literature suggest that this approach reduces errors-in-variables problems and thus gives UIP a fairer chance to be born out by the data (Lothian and Simaan, 1998; Chinn, 2006). The results are very similar (table 2.14).

Sofar, the results suggest that risky rate co-movement differs in important ways from safe rate co-movement across exchange rate regimes. The presented co-movement analysis, however, does not distinguish between co-movement due to correlated exogenous shocks and co-movement due to endogenous transmission. For this reason the following section analyzes the response of pegs' and floats' interest rates to monetary policy shocks from financial center countries.

2.2.2. Financial center monetary policy transmission to pegs and floats

The second piece of evidence for the declining decoupling power of floating exchange rates in shielding local risky rates is born out by the study of the international transmission of financial center monetary policy shocks. For this purpose I look at the international spillover effects of two important financial centers' monetary policy: the Bank of England's discount rate policy, prior to 1914, and the Federal Reserve's interest rate policy, after 1973. The focus lies on discerning systematic differences in the reaction of pegs' and floats' interest rates. In contrast to the previous section's co-movement analysis this section makes causal claims as to the effectiveness of floating exchange rates in shielding local interest rates from monetary policy conducted in important financial centers.

Today, the U.S. dollar is an important vehicle currency that underpins today's global financial system.[24] U.S. monetary policy decisions thus have global reach (see Kim, 2001; Canova, 2005; Uribe and Yue, 2006; Ehrmann and Fratzscher, 2009; Maćkowiak, 2007; Craine and Martin, 2008; Asgharian and Nossman, 2011; Bluedorn and Bowdler, 2011; Hausman and Wongswan, 2011; Cetorelli and Goldberg, 2012; Chudik, Smith et al., 2013; Georgiadis, 2016; Kose et al., 2017). More particularly, Fed policy has been shown to influence risk appetite not only in the U.S. (Bekaert, Hoerova and Duca, 2013; Gertler and Karadi, 2015) but globally (Miranda-Agrippino and Rey, 2015; Rey, 2016). Of particular interest here are recent findings that that U.S. monetary policy today has international knock on effects irrespective of exchange

[24]The U.S. dollar at the beginning of the 21st century makes up more than 30% of central banks' foreign exchange reserves, accounts for more than 40% of global exchange market turnover, 40% of OTC derivatives and the majority of international banking liabilities (Frankel, 2011). U.S. dollar-denominated assets of banks outside the U.S. amounts to around 10 trillion USD, about equalling the total assets of the U.S. commercial banking sector (Shin, 2012). USD credit extended by banks and bond investors to non-financial sector borrowers outside the USA is about 7 trillion USD. Also, around 80% of USD-denominated bank credit issued outside the U.S. has been issued by non-U.S. banks (see McCauley, McGuire and Sushko, 2015). Furthermore U.S. equity markets constitute between 30 and 40% of global equity market capitalization and between 2000 and 2013 U.S. government and corporate bonds constituted between one third and one half of global bond market capitalization. About two thirds of the global stock of corporate bonds outstanding are issued in USD (according to Meryll Lynch Global Corporate and High Yield Index).

rate regime (Passari and Rey, 2015; Rey, 2016).[25]

Prior to 1914 the pound sterling was the world's leading foreign reserve-currency and its leading vehicle currency.[26] Thus financial conditions in London had international ramifications. Indeed in the late 19th century the global reach of U.K. monetary policy found its expression in the famous hyperbole that, if the Bank of England raised its discount rate to 7 percent, it could even "attract gold from the moon".

To see how effective floating exchange rates have been in decoupling domestic rates from financial center shocks I compare the interest rate responses of pegs and floats to U.K. monetary policy shocks prior to 1914 and U.S. monetary policy shocks in the late 20th and early 21st centuries. For this purpose this section introduces a monetary policy shock measure for the Bank of England (BoE) from 1880 to 1913, as well as a new dataset of hand-collected monthly policy- and risky rates. The BoE policy shock measure was inspired by the narrative policy shock measure introduced by Romer and Romer (2004) in that it isolates exogenous movements in the policy rate by accounting for the information available to policymakers at the time of their policy decision. On the basis of the new pre-1914 shock measure for BoE policy and the post-1966 shock measure by Romer and Romer (2004) for Fed policy it is then possible to analyze the differential response of pegs and floats to financial center monetary policy shocks in the pre-1914 and post-1973 eras.

Methodological approach

In order to analyze the international response to monetary policy in the financial center I estimate a set of impulse response functions through local projections (Jorda, 2005).

$$\Delta_{h+1} r_{k,t+h} = \alpha_k^h + \sum_{m=0}^{12} \beta_m^h \Delta r_{k,t-m} + \sum_{m=0}^{12} \gamma_m^h S_{t-m} + \sum_{m=0}^{12} \delta_m^h S_{t-m} float_{k,t} + u_{k,t+h}, \quad h = 0, ..., H \tag{2.8}$$

[25]The transmission of U.S. monetary policy occurs through different channels. First, it affects the balance sheet capacity of global financial intermediaries that fund themselves in USD. This channel will be fleshed out in a model and quantitatively assessed in the second part of this paper. Relatedly, if contractionary U.S. monetary policy raises the USD exchange rate this impairs the risk-taking capacity of financial institutions whose USD liabilities exceed their USD assets (Bruno and Shin, 2015). Cetorelli and Goldberg (2012) show that U.S. monetary policy influences global banks' internal funding markets. Also, U.S. monetary policy may directly act as a focal point that synchronizes perceptions of asset price-risk among international investors (see Bacchetta and van Wincoop, 2013).

[26]The vast majority of foreign public debt was denominated in pound sterling (Chiţu, Eichengreen and Mehl, 2014*a*), about 60% of world trade was invoiced in this curreny (Frankel, 2011; Eichengreen and Flandreau, 2012), it made up the majority of central bank foreign exchange reserves (Lindert, 1969) and London was the world's preeminent financial hub dominating the global foreign exchange market (Flandreau and Jobst, 2005, 2009). At the same time the London stock exchange was the world's most extensive market place at which borrowers and lenders from all over the world were matched. About one third of all negotiable securities in the world were quoted there (Cassis, Grossman and Schenk, 2016, p.299). The Bank of England was ascribed the role of "conductor of the international orchestra" of central banks (Kindleberger, 1984; Eichengreen, 1987).

where α_k are country-fixed effects, $\Delta_{h+1} r_{k,t+h}$ are h-year changes rates in the interest rate r_k and $u_{k,t+h}$ are error terms.[27] The $\{\gamma_0^h\}_{h=1,\ldots,H}$ in expression 2.8 allows me to sketch out the average behavior of international risky and safe interest rates over the H months following a U.S. policy rate shock S_t (post-1973) or a U.K. discount rate shock (pre-1914), while the $\{\delta_0^h\}_{h=1,\ldots,H}$ allow me to investigate the differential in responses between pegs and floats. $float_{k,t}$ is a dummy variable that is 1 in periods when country k's exchange rate relative to the center country floats, has been floating for the previous 12 months, and will be floating for the following 36 months ($H = 36$). Analogously the dummy is 0 in months when the exchange rate is fixed in the current month, was fixed throughout the previous 12 months and continuous to be fixed in the 36 months to come. This definition ensures that estimated impulse response functions clearly distinguish between pegs and floats; any episodes in which countries switch from floating exchange rates to fixed ones and vice versa are thus eliminated from the sample. In all cases I make use of the bilateral peg dummy described in section 2.2.1.

In order to take into account differences in capital account openness I drop all country-month observations affected by capital controls from the sample in order to focus on the role of the exchange rate regime. For this purpose I use the capital control indicator described in section 2.2.1.

Data

Pre-1914 BoE monetary policy shocks: Prior to 1914 the BoE's key policy rate was its discount rate, i.e. the rate at which eligible paper (mostly 3-month bills of exchange) could be exchanged for BoE notes at the BoE's discount window.[28] In the spirit of Romer and Romer (2004) I consider a monetary policy rate shock measure which tries to correct for the endogeneity in discount rate changes by purging them of information that was available to market participants and policymakers' at the time of the policy decision. The resulting shock measure constitutes discount rate changes that deviated from the rules implicit in the Gold Standard, and that came as a surprise to market participants and the wider public.

On which information was the BoE's discount rate decision based? Most crucially prior to 1914 the BoE's discount rate decision was informed by the composition of its balance sheet. Changes in the discount rate were primarily targeted at ensuring the gold-convertibility of BoE notes through a sufficiently high ratio of liquid assets (i.e. gold or assets that were quickly convertible into gold) to liquid liabilities. Most important in this respect was the "proportion". The proportion was the ratio of total reserves to the sum of deposits and post bills.[29] Total reserves were made up of notes, gold- and silver coins. The notes-part of total reserves was made up of "notes in the bank", i.e. notes that were backed by the Issue Department of the

[27] This specification allows for a contemporaneous effect of the shocks S_t on the interest rate.

[28] The following description of BoE monetary policy operations draws extensively from Sayers (1976).

[29] Deposits included public and private deposits, the majority being private. Post bills constituted an alternative to bank notes, but were safer to send through post. They constituted only a minor part of the Banking Department's liabilities.

Bank of England with gold bullion or gold coin.[30] The proportion's prominence in the central bankers' minds is evident in the fact that it was calculated and reported in the BoE's daily accounts, with occasional counterfactual proportions being calculated and scribbled into the daily accounts by the directors.

Another item in the BoE's balance sheet that was influential in deciding upon the discount rate level was the weekly change in the value of bills discounted. If at the going rate the discount window was accessed frequently, and the resulting asset swap from (gold-backed) notes to discounted bills quickly lowered the BoE's Banking Department's reserves the BoE was more inclined to increase its discount rate. In this way discount rate policy was systematically countercyclical to money demand and economic activity more generally.

As regards timing, an up to date version of the balance sheet was presented to BoE directors every morning, including on Thursdays when the Court of Directors usually accepted the discount rate change proposed by the Governor. On Thursday mornings the Directors would be handed an individual copy of the BoE's balance sheet, which also was the last piece of information available to the Governor on the basis of which to make his discount rate proposal. Usually the bank's Governor stuck to the discount rate proposal already made by the Committee of Treasury on Wednesdays. Formally however the Governor had the right to deviate from this proposal. Thus if the Thursday morning balance sheet should contain some new information according to which the Governor saw the discount rate proposal from the previous day unfit he could change it. In this sense the Thursday morning balance sheet, with the latest figures from Wednesday constituted the latest information set of decision makers at the BoE.[31]

Given this balance sheet information I regress the weekly change in the BoE's discount rate (Δi_t) on the proportion (p_t), the change in the proportion, the change in discounts (Δd_t), as well as 1 lag of all these. Finally I add the previous week's discount rate level (i_{t-1}) among the regressors, in order to capture mean reversion in the discount rate.

$$\Delta i_t = \alpha + \beta i_{t-1} + \sum_{m=-1}^{0} \gamma_m p_{t+m} + \sum_{m=-1}^{0} \delta_m \Delta p_{t+m} + \sum_{m=-1}^{0} \eta_m \Delta d_{t+m} + S_t \tag{2.9}$$

The estimated residual $\widehat{S}_t$ constitutes the resulting monetary shock measure.[32] This shock series is displayed in figure 2.2 (this is the monthly mean of the weekly shocks).

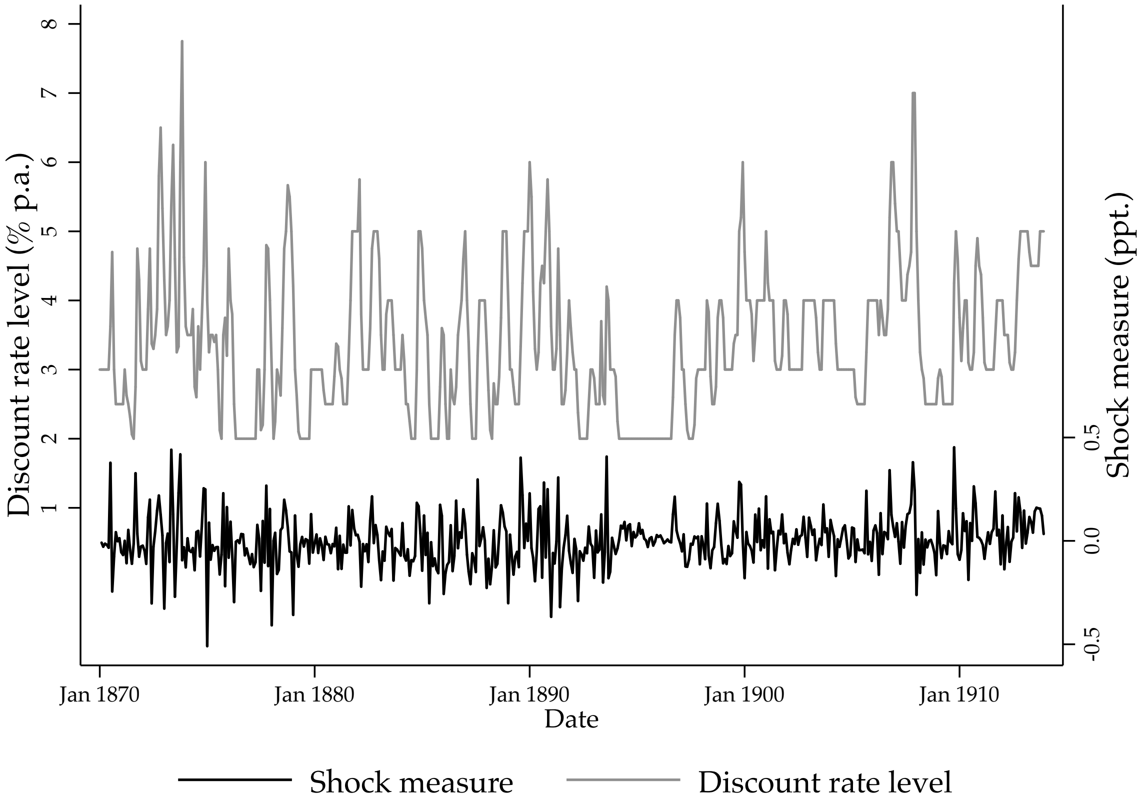
As a validation exercise I check whether the weekly shock series is correlated with changes

[30] The gold backing exempted a fiduciary note issue whose amount was increased on an irregular basis.

[31] Occasionally, in response to a crisis situation, the Governor had the power to enact a so-called "Governor's rise", i.e. an unscheduled change in the discount rate which then would be retrospectively accepted by the following session of the Court of Directors. In these cases I take the Governor's information set to have been the balance sheet at the day of the unscheduled discount rate change, containing balance sheet information up to the previous day.

[32] In contrast to the shock measure proposed by Romer and Romer (2004) this setup does not include any forward looking information. Indeed professional economic forecasts only became a common feature of economic policy making later. As such the focus on backward looking balance sheet information, provided though on a daily basis, reflects one of the more mechanistic aspects of central banking under the gold standard.

Figure 2.2: *Bank of England's discount rate and monetary shock measure*



in the mentioning of the BoE's discount rate policy in the day following the discount rate decision. A surprising discount rate change should be reflected in a subsequent increase in the news coverage of the policy move. For this purpose I ran a word search for the term "bank rate" in the daily newspaper *The Guardian*. I then regressed the absolute value of the weekly discount rate shock on the change in word counts for "bank rate", as well as absolute changes in the discount rate. The results are shown in table 2.5. The correlation between the absolute discount rate shock and the word count is highly significant. Thus the calculated shock measure reflects policy moves that were perceived as surprising enough by contemporary observers to warrant increased news coverage.

Post-1973 Fed monetary policy shocks: For the post-1973 era I use the narrative shock measure that was introduced by Romer and Romer (2004) and subsequently extended by Coibion et al. (2012). This shock measure attempts to isolate exogenous variation in the intended Federal Fund rate by purging it from information about the economy that central bankers had at the time they decided upon their new policy rate. In contrast to the previously introduced shock measure for the BoE, today's central bankers base their decision not mainly on the central bank's balance sheet, but instead on the information they have about the past, present and expected future behavior of the economy. Thus Romer and Romer (2004)

Table 2.5: *Validation: Correlation with word counts from The Guardian*

	(1)	(2)
"Bank rate" count	0.0279**	0.0269**
	(2.3840)	(2.3383)
Month FE	No	Yes
Observations	2008	2008
adjusted R2	0.90	0.91

Dependent variable: absolute value of discount rate shock. Additional controls: absolute changes in the discount rate and a constant. t-statistics in parentheses.

used the Federal Reserve's internal estimates and forecasts about past, current and future inflation, real output and unemployment to purge the intended Federal Fund rate of any anticipated movements and obtain a residual that can be interpreted as a monetary policy shock (analogously to equation 2.9). I use this monthly narrative shock series as the interest rate shock measure S_t from 01:1973 until 12:2008, in order to assess the impact of U.S. monetary policy on pegs' and floats' interest rates according to the local projection described earlier (equation 2.8).

Pre-1914 monthly interest rate data: In order to investigate the international impact of pre-1914 U.K. monetary policy on pegs and floats respectively I collected monthly short-term policy rates and risky rates for Sweden, Denmark (pegs), Spain, Portugal (floats) and Japan (float until 1897 and peg afterwards).[33] The risky rate is either a bank lending rate or a corporate bond yield index which I constructed from the coupon rates and bond prices reported in local newspapers. The corporate bond yield index is an equal weighted average of the corporate bond yields of private companies. Importantly, the bond yield index only makes use of bonds that were denominated in local currency.[34]

Post-1973 monthly interest rate data: For the post-1973 years, the monthly time series for safe and risky rates come from the same sources as the annual data do: the IMF's International Financial Statistics, national statistical offices or national central banks. For the risky rate I use lending rates for unsecured bank lending to private corporations and households of relatively short maturities. The safe rate usually is the central bank's policy rate, a short-term money market rate or the current yield of a short-term government bond. In total the sample covers 48 countries (see table 2.17).

[33] In Portugal gold convertibility ceased in 1891 from which point on the discount rate is not used to stabilize the exchange rate. In Spain gold convertibility ceased in 1883 and a de facto fiat money system was established as silver convertibility became irrelevant (Martín-Aceña, 2007).

[34] While floating pound-sterling denominated bonds on the London Stock Exchange was a first choice for many companies located in peripheral economies, a substantial fraction of bonds was nevertheless issued in domestic currency in the home market (Mitchener and Pina, 2016).

Results

Pre-1914 Bank of England policy spillovers: The top two panels in figure 2.3 displays how the world reacted to a +1 ppt increase in the BoE's discount rate in the first era of financial globalization prior to 1914. The left figure displays how safe policy rates of pegs (black solid line) and floats (blue dashed line) responded. As can be seen, floats exhibited no response, while pegs exhibit a full +1 ppt increase in their safe rate within about 12 months. The blue points on the floats' impulse response indicates whether the floats' response differs statistically significantly from the pegs' response according to a Wald test for equality of responses.

The upper right panel displays the equivalent IRFs for risky rates. Again the pegs exhibit a complete pass-through while floats respond little. In general floating exchange rates were an effective instrument for decoupling domestic interest rates – risky and safe – from BoE policy.

Post-1973 Federal Reserve policy spillovers: The lower half of figure 2.3 shows the differential effect of Fed interest rate shocks on pegs and floats. For safe rates, the pass-through among pegs is complete and takes place within six months. Floats' safe rates also react, but far less so, exhibiting about two fifth, or 40%, of the response of floats. The floats' response is indicative of the long-run increase in the global synchronization of underlying economic fundamentals (Bordo and Helbling, 2011), which induces central banks to synchronize policy rates, even among floats. The difference to the pegs' response, however, is still significant at the 95%-level throughout the 36-month horizon.

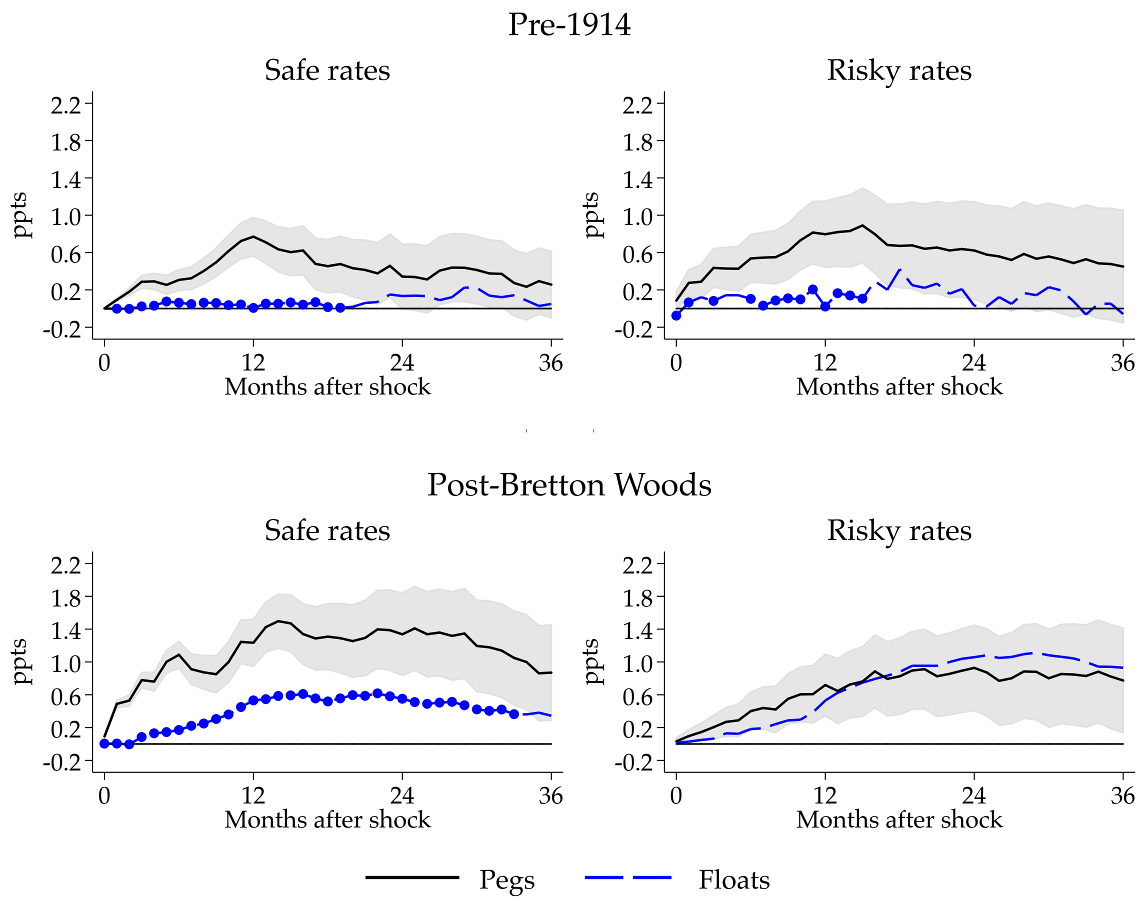
The difference between pegs and floats, however, is no longer significant for risky rates. In contrast to the early 20th century floating exchange rates have become much less effective in insulating an economy's risky rates from U.S. monetary policy shocks in the Post-Bretton Woods era of financial globalization. In particular, in the aftermath of a contractionary U.S. policy rate shock, the spread of floats' risky rates over floats' safe rates increases by around 0.4 ppts, closing the gap to the pegs' response. In contrast, the pegs' response does not exhibit a similar increase in spreads. All movement in the pegs' risky rate comes from movement in the safe rate.[35]

I also considered a subsample of advanced economies, on which most of the recent evidence in the dilemma literature is based on (Passari and Rey, 2015; Rey, 2016). I find that for advanced economies post-1973, floating exchange rates are associated with somewhat more risky rate independence in the short-run. After 12 months, however, the peg-float difference has again vanished (see figure 2.7 in the appendix).[36]

[35] The risky rate response for pegs is somewhat more sluggishly than the safe rate response. One reason for this might be that the risky rates are mostly bank lending rates, which have been shown to exhibit some rigidity (see Gerali et al., 2010).

[36] It is well known that many emerging markets' ''safe rates" contain a risk premium (Mauro, Sussman and Yafeh, 2002), which quickly react to U.S. monetary policy.

Figure 2.3: *Pegs' and floats' response to +1 ppt policy rate shock in financial center*



Solid black line – response of pegs; dashed blue line – response of floats; Blue circles indicate the point-wise rejection of the null hypothesis that the peg response equals the float response at the 90% significance level, according to a two-sided Wald test. Confidence bands calculated on the basis of Driscoll-Kraay standard errors (accounting for 36 monthly lags of autocorrelation). All specifications include country fixed effects. Pre-1914 sample: 1880:1 to 1913:12; Post-Bretton Woods sample: 1973:1 to 2010:12.

In sum, these results underscore the long-run decline in the ability of floating exchange rates to decouple local risky rates. The absence of extensive risk premium spillovers in the early 20th century rendered floating exchange rates effective in decoupling safe, as well as risky rates from their global counterparts. By the late 20th century, however, risk premium spillovers have become pervasive enough to seriously qualify the effectiveness of floating exchange rates with respect to risky rates.

2.3. Why do risk premiums co-move?

What lies behind the late 20th century rise in international risk premium synchronization? The early and late 20th century financial globalizations were both underpinned by financial openness. Financial openness allows international investors to engage in arbitrage until return differentials between assets within the same risk class are eliminated, and hence risk premiums are equalized (see Dedola and Lombardo, 2012).[37] Explanations based solely on financial openness, however, beg the question of why risk premium co-movement among floats is specific to the late 20th century and did not already occur in the early 20th century (see Quinn and Voth, 2008). To understand this, it is key to understand the differences in the financial institutions that underpinned both eras of financial globalization. In particular, the growing importance of globalized banks, and the interplay of leverage constraints and mark-to-market accounting they embody.[38]

2.3.1. The international risk-taking channel

To see how the combination of leverage constraints and mark-to-market accounting in global banks opens the door to extensive risk premium spillovers, even among floats, consider the following: When leverage-constrained banks become marginal investors in risky asset markets, bank leverage can become a driving force for excessive movements in risky assets' prices (Brunnermeier and Pedersen, 2009; Danielsson, Shin and Zigrand, 2012; Adrian and Boyarchenko, 2013*b*).[39] Hence the movements in risky rates will be disproportional to movements in safe rates, which are set by the central bank. In an open economy this gives rise to a conflict between the international non-arbitrage conditions for safe and risky assets, because the nominal exchange rate can adjust to satisfy only one of the two. For example, the nominal exchange rate may satisfy the non-arbitrage condition for safe rates but not that for risky rates. This however is no equilibrium, because investors will shed the overpriced risky asset and buy the underpriced one until risky asset prices have adjusted sufficiently that the non-arbitrage condition for risky assets is satisfied. It is in this sense that risk premiums can overwhelm floating exchange rates and spill over from one currency area into another. Note the twofold role of banks here. First, as marginal investors their leverage constraint drives a wedge between the movement in safe and risky asset returns, and hence opens up the conflict for the nominal exchange rate to either equalize expected returns for safe or risky rates. Second, banks' international arbitrage activity ensures that the disproportional movement in risky rates spills over into the rest of the world.

From an individual bank's perspective the corresponding events depict themselves as

[37] Also see Kollmann, Enders and Müller (2011) and Alpanda and Aysun (2014) for theoretical accounts in which the international equalization of returns is driven by the optimizing behavior of a global bank, that exploits arbitrage opportunities across regions.

[38] While I concentrate on the explanatory power of differences in financial institutions Jordà et al. (2017*b*) discuss several alternative explanations. For example, the pre-1914 Gold Standard introduced a desynchronizing force into global finance, because one region's gold inflows constituted another region's gold outflows. Thus, in contrast to today's fiat money system global liquidity supply in the 19th century Gold Standard was inelastic, rendering synchronized risk-taking less likely. Behavioral explanations that attribute financial excess variation to systematic mis-judgements in human psychology (Kahneman and Tversky, 1979; Shiller, 2000; Akerlof and Shiller, 2010) and to collective manias and panics (Kindleberger, 1978) face the difficulty of having to explain why international investors' behavior differs between the two eras of financial globalization, although they presumably were subject to the same cognitive constraints.

[39] Adrian, Etula and Muir (2014) and Adrian, Moench and Shin (2016) present empirical evidence that leverage-constrained banks are indeed influential marginal investors.

follows: a fall in risky asset prices, that is not exactly offset by a movement in the exchange rate, affects the bank's leverage. Subject to a leverage constraint, and because issuing new equity is costly, the bank sells risky assets to fulfill its leverage constraint. The bank, however, does not sell risky assets indiscriminately. It sells home and foreign risky assets in a way that ensures that the non-arbitrage condition between the two is satisfied. This chain of events plays out simultaneously in different currency areas, because it pivots around a fall in global asset prices that affects banks everywhere. In this way risk-taking becomes synchronized, even among floats.[40]

2.3.2. *Early vs. late 20th century financial institutions*

How did financial globalization in the early 20th century look like to avoid extensive risk premium spillovers? In the early 20th century, financial globalization in general took the form of equity and debt securities traded on a stock exchange – first and foremost in London, but also in Paris and other Western European financial centers. The securities traded on these stock exchanges were a popular asset type with contemporary investors (Hoffman, Postel-Vinay and Rosenthal, 2009). By the late 19th century, after decades of continuous refinements, stock exchanges had struck a balance between competition and market regulations that (international) investors and creditors preferred over alternative modes of intermediation (Cassis, Grossman and Schenk, 2016, ch.11).

Among the financial institutions active on the stock exchange risk-sensitive funding and leverage constraints were less of a concern than they are for big global banks today. Investment trusts[41] and closed-end mutual funds were among the most active in underwriting overseas corporate securities. These institutions commonly pursued a long-term buy-and-hold investment strategy.[42] In the meantime, the composition of their portfolio, let alone its market value, could be hard to find out. Owing to the conservative balance sheet structure of these financial institutions, investors however also had less to worry about in the first place. Investment trusts typically invested less in equity than they issued ordinary shares themselves (Rutterford, 2009). The upshot of all this was the relative irrelevance of leverage constraints, and hence the absence of procyclical intermediary risk-taking. To the contrary, in times of crisis important global investors acted in a stabilizing way, by taking on debt in order to buy assets at depressed prices (Chambers and Esteves, 2014) .

Wealthy private individuals were another major participant on stock exchanges (Michie, 1986), contributing an estimated 5 to 10% of British capital investment abroad (Feis, 1964, p.24). Such investment typically is not affected by leverage constraints as it is rarely levered in the first place.

[40] Note that the international risk-taking channel described here is different from the one described by Bruno and Shin (2015), who focus on exchange rate valuation effects on banks' balance sheets.

[41] The term investment trust here is meant to include investment trust companies, which are no legal trusts, but which made up the majority of investment trust after the 1870s.

[42] Consequently, these financial institutions had little turnover and made no attempt to act as market makers (Chambers and Esteves, 2014), a role which was firmly in the grips of stock exchanges.

Finally, banks also played a role in early 20th century financial globalization. Especially so in Germany and France, where financial systems were more bank-based to begin with. However, banks tended to finance themselves through a comparatively stable base of deposits (Feis, 1964). This also was the case in Germany where a handful of great universal banks played a dominant role in underwriting, distributing and partly holding securities. Thus, to the extent that they were influential in foreign investment, the depositor-enforced leverage constraints of pre-1914 banks were most likely less stringent than those of today's banks, whose leverage faces surveillance from financial regulators and wholesale money market creditors alike.

The financial globalization that started in the late 20th century differed in crucial ways from that earlier in the 20th century. It was critically underpinned by large global banks – financial intermediaries that face leverage constraints and mark their assets to market.[43] Typical exemplars of today's global financial intermediaries are Wall Street investment banks and large European universal banks. These institutions' assets to capital ratio – a measure of their leverage – can be as high as 35 (see Eichengreen, 1999), but more typically centers around 10. These are commonly considered to be leverage-constrained institutions.[44]

Today's global banks have a much broader range of operations than banks in the early 20th century. They are influential players on many asset markets, such as commodity and derivative exchanges, the interbank bond market and over the counter (OTC) transactions. Due to their size banks can often act as market makers. The stock exchange, the unrivalled market place for securities in the early 20th century, has become only one among many market places over which global banks hold considerable sway. As a consequence, global banks' risk-appetite makes itself felt in asset markets throughout the world.

Vice versa, asset price movements throughout the world make themselves felt in global banks' risk-taking capacity. This is because the late 20th century has witnessed the spread of mark-to-market accounting practices. By comparison, pre-1914 investment companies, were intransparent. If they made their portfolios public at all, they did not mark their assets to market. Only after 1945 did business laws start to require financial trusts to reveal the current market value of investments in some way. It was even later in the 20th century that mark-to-market was turned into standard accounting practice (Newlands, 1997, ch.12). By the late 20th century, however, mark-to-market accounting had become so ingrained in global finance, that asset price movements anywhere could impact banks' balance sheets everywhere.

One particular type of formal leverage constraint that has come to characterize modern

[43] Many of these large banks were the result of mergers in which former investment banks became part of universal institutions (Cassis, Grossman and Schenk, 2016, p.157).

[44] The exact forms and origins of the leverage-constraints faced by these institutions differ. Partly they are market enforced, partly they take the form of regulatory requirements. Leverage-constraints commonly address the need of the intermediary's creditors to counter problems of agency – ensuring the intermediary has enough 'skin in the game'. The late 20th century rise in bank leverage and leverage constraints thus are related to various factors that are beyond the scope of this paper, such as asymmetric remuneration schemes for bank management, limited liability, government guarantees, such as deposit insurance, and the preferential tax treatment of debt.

finance are value-at-risk (VaR) constraints.[45] In its simplest form a VaR constraint states that a bank's equity has to be sufficient to cover bad scenario losses. VaR is a risk-management metric that has its origins in the financial innovations of the 1970s and 1980s that led to a proliferation of leverage and a growing need for an organization-wide risk metric. At the same time innovations in information technology and the falling price of computation power rendered VaR measures that had been proposed theoretically a few decades earlier practical (see Markowitz, 1952; Roy, 1952; Tobin, 1958; Treynor, 1961; Sharpe, 1964; Lintner, 1965; Mossin, 1966). As a consequence, VaR-like measures sprung up in trading environments during this period (see Lietaer, 1971; Garbade, 1986, 1987). Over the following years the spread of internal risk management techniques fed back into financial regulation and vice versa. In this way VaR-based measures spread even further and became enshrined into international financial regulation, such as the Basel accords or the EU's capital adequacy directive (CAD) (Holton, 2003).[46]

In order to quantitatively assess the extent to which the rise of VaR-constrained financial intermediaries can account for the observed international spillovers in risk premiums the following section introduces an international banking model in which banks mark their assets to market and face a VaR constraint.

2.4. A model of VaR constrained banking

This section rationalizes the empirical findings presented earlier through a two-country banking model with value-at-risk (VaR) constrained banks. In the two-country model leverage-constrained banks, that mark-to-market their assets, are marginal investors in global asset markets. Banks maximize the expected discounted utility streams of their local shareholders. They invest in an international portfolio of risky assets. This is funded through equity, as well as domestic and foreign debt, for which they pay domestic and foreign safe rates. The VaR constraint limits the banks' asset to equity ratio. Because the expected returns on risky assets exceed the costs of debt financing banks lever up to their VaR constraint.

[45] A new literature on VaR based and related funding constraints has recently sprung up (Brunnermeier and Pedersen, 2009; Danielsson, Shin and Zigrand, 2012; Adrian and Boyarchenko, 2013*a*). One particular advantage of this new generation of financial friction models over conventional credit-channel formulations based on Bernanke, Gertler and Gilchrist (1999) and Kiyotaki and Moore (1997) is that they generate procyclical risk-taking. Empirically, Adrian, Etula and Muir (2014) and Adrian, Moench and Shin (2016) and have recently shown that intermediary leverage is a key for explaining observable asset price patterns (also see He and Krishnamurthy, 2017). For this reason I model the bank's funding constraint as a VaR constraint, which states that the bank's value at risk needs to be covered by its equity.

[46] As a consequence a new literature on VaR-based and related risk-sensitive funding constraints has recently sprung up (Brunnermeier and Pedersen, 2009; Danielsson, Shin and Zigrand, 2012; Adrian and Boyarchenko, 2013*a*). One particular advantage of this new generation of financial friction models over conventional credit-channel formulations based on Bernanke, Gertler and Gilchrist (1999) and Kiyotaki and Moore (1997) is that they generate procyclical leverage. Empirical support for this framework comes from Adrian, Etula and Muir (2014) and Adrian, Moench and Shin (2016) who have recently shown that intermediary leverage is a key for explaining observable asset price patterns.

The banks' optimizing behavior gives rise to arbitrage activity that ensures that the price for domestic debt equals the price for foreign debt plus the expected exchange rate change. In other words, uncovered interest rate parity holds for safe rates (in the linearized model). In equilibrium a similar non-arbitrage condition has to hold for domestic and foreign risky assets. However, when safe and risky rates do not move one-to-one, this gives rise to a conflict between the non-arbitrage conditions for safe and risky assets. The nominal exchange rate can adjust to satisfy only one of the two. For example, the nominal exchange rate may satisfy the non-arbitrage condition for safe rates but not that for risky rates. This however is no equilibrium, because investors will shed the overpriced risky asset and buy the underpriced one until risky asset prices have adjusted sufficiently, so that the non-arbitrage condition for risky assets is also satisfied. It is in this sense that risk premiums can overwhelm floating exchange rates and spill over from one currency area into another.

In the model, safe and risky rates do not move one-to-one, due to the interplay of leverage constraints, mark-to-market accounting practices, and costly equity adjustment. Consider any shock that puts downward pressure on risky asset prices. The drop in risky asset prices erodes foreign and home bank equity. Subject to VaR constraints, and because raising new equity is costly, the banks will adjust their leverage by selling risky assets, putting even more downward pressure on risky asset prices. The resulting sell-off of risky assets generates an excessive increase in risky rates.

Note the twofold role of banks here. First, as marginal investors they drive a wedge between the movements in safe rates and risky rates, and hence open up the conflict for the nominal exchange rate to either equalize expected returns for the one or the other. Second, banks' international arbitrage activity ensures that any excess movement in risky rates spills across borders.

2.4.1. Model outline

Figure 2.4 displays the model's two banks and their balance sheets. I outline the model from the *home* (H) bank's perspective. The *foreign* (F) bank's problem is symmetric, and foreign variables are denoted with a star superscript (*). In order to clarify the proposed international risk-taking channel the model exposition focuses on international capital markets and abstracts from all other markets.[47]

The *Home* bank maximizes the expected discounted utility stream of its shareholders, who receive utility from consumption (c_t). Shareholder income is made up of dividends (m_t) and a fixed endowment (y), so that $c_t = m_t + y$.[48] The bank buys risky home and foreign assets (b_t^h and b_t^f) at market prices (q_t^h and q_t^f), and the bank funds these risky asset purchases through equity (k_t), as well as home and foreign debt (d_t^h and d_t^f) for which it pays risk-free rates (i_t^h and i_t^f). The superscript h denotes assets and debt denominated in home currency, and f those

[47]The model abstracts from consumer price dynamics. All variables are nominal and banks maximize expected nominal profits, effectively assuming a stable price level.

[48]The endowment reflects any other income, besides bank dividends, that shareholders receive.

Figure 2.4: *Model structure*

Home bank		Foreign bank	
Risky assets h	Equity h	Risky assets f	Equity f
	Debt h		Debt f
Risky assets f	Debt f	Risky assets h	Debt h

denominated in foreign currency. The bank is subject to a VaR constraint, which states that the bank's (book) equity must suffice to cover its value at risk.[49] The bank's maximization problem is furthermore constrained by the balance sheet identity and the law of motion for equity, which states that equity equals previous period's equity, plus profits, minus dividend payouts:

$$\max_{\{c_t, b_t^h, b_t^f, d_t^h, d_t^f, k_t\}_{t=0}^{\infty}} \mathbb{E}_0 \Big\{ \sum_{t=0}^{\infty} \beta^t u(c_t) \Big\} \tag{2.10}$$

$$\text{s.t. equity law of motion:} \quad k_t = k_{t-1} + \Pi_t - c_t + y \tag{2.11}$$

$$\text{balance sheet ID:} \quad k_t + d_t^h + d_t^f e_t = q_t^h b_t^h + q_t^f b_t^f e_t \tag{2.12}$$

$$\text{VaR:} \quad \mathbb{E}_t\{VaR_{t+1}\} \leq k_t, \tag{2.13}$$

where capital (k_{t-1}) and beginning of period realized profits (Π_t) are state variables, y is a fixed endowment and e_t is the nominal exchange rate (Home currency/Foreign currency). The utility function has the CRRA form $u(c_t) = (c_t^{1-\sigma} - 1)/(1-\sigma)$. In the context of the presented banking model $\sigma > 0$ can be interpreted as a dividend smoothing motive. This also implies that issuing new equity ($m_t < 0$) is costly.

Profits (Π_t) equal the expected returns from investing in risky assets, minus previous period's bank equity, minus the cost of debt and the cost of adjusting the foreign portfolio:

$$\begin{aligned}\Pi_t = {} & \tilde{q}_t^h b_{t-1}^h + \tilde{q}_t^f b_{t-1}^f e_t - i_{t-1}^h d_{t-1}^h - i_{t-1}^f d_{t-1}^f e_t - k_{t-1} \\ & - \frac{\tau}{2}\left(d_{t-1}^f - o_d^f\right)^2 - \frac{\tau}{2}\left(b_{t-1}^f - o_b^f\right)^2.\end{aligned} \tag{2.14}$$

[49] The VaR constraint is based on book equity, because it features prominently in banking regulation as well as in banks' annual reports, for example in return on equity figures (Adrian, Boyarchenko and Shin, 2015). Furthermore, in their empirical study on intermediary asset pricing Adrian, Moench and Shin (2016) show that broker-dealer leverage calculated with book equity, not market equity, is a key state variable for asset pricing. The VaR constraint is formulated as an inequality constraint $\mathbb{E}_t\{VaR_{t+1} \leq k_t\}$, giving rise to a Kuhn-Tucker optimization problem. However, as long as the expected return on risky assets exceeds the cost of debt-financing, and as long as the cost of equity exceeds the cost of debt, the bank will lever up to the constraint and buy as many risky assets as possible, i.e. in equilibrium the VaR constraint will hold with equality.

$\tilde{q}_t^h$ and $\tilde{q}_t^f$ denote the gross return of the two risky assets. This gross return is comprised of a fixed coupon payment (c^h and c^f), the risky asset's price (q_t^h and q_t^f) and a repayment rate ($D_t^h, D_t^f \in (0,1)$), where $\tilde{q}_t^h \equiv D_t^h(q_t^h + c^h)$.[50] The risky assets can be thought of as corporate bonds with a default rate $1 - D_t$, i.e. only a fraction D_t of the risky assets pays a coupon and can be sold at price q_t this period. The remaining fraction $1 - D_t$ becomes worthless and pays no coupon.

The bank receives funding in H and F currency at the safe policy rates i_t^h and i_t^f. On the liability side there furthermore is bank capital – the bank's equity. As a consequence of $\sigma > 0$ the bank will not simply fulfill its VaR constraint through raising new equity. Instead, the bank will partly fulfill its VaR constraint through adjustments in risk-taking. Finally, o_d^f and o_b^f denote steady state gross foreign asset holdings. Foreign portfolio adjustment costs are needed in order to pin down steady state foreign asset- and liability holdings (see Schmitt-Grohé and Uribe, 2003; Benigno, 2009).

The bank's value at risk is defined as its bad scenario profits for next period

$$-\mathbb{E}_t\{VaR_{t+1}\} \equiv \mathbb{E}_t\{\Pi_{t+1}^{low}\} = \tilde{q}^{h,low} b_t^h + \tilde{q}^{f,low} b_t^f \mathbb{E}_t\{e_{t+1}\} - i_t^h d_t^h - i_t^f d_t^f \mathbb{E}_t\{e_{t+1}\} - k_t$$
$$- \frac{\tau}{2}\left(d_t^f - o_d^f\right)^2 - \frac{\tau}{2}\left(b_t^f - o_b^f\right)^2, \tag{2.15}$$

where $\tilde{q}^{h,low}$ denotes bad scenario gross returns on the risky home asset: $\tilde{q}^{h,low} \equiv D^{h,low}(q^{h,low} + c^h)$. $D^{h,low}$ and $q^{h,low}$ stand for a high default rate- and low asset price state.[51] Given a stationary distribution of risky asset prices, $q^{h,low}$ denotes a specific low percentile of that distribution.[52]

The safe rate follows an AR(1) process

$$i_t^h = (1 - \chi^i) i^h + \chi^i i_{t-1}^h + \epsilon_t^{h,i}, \tag{2.16}$$

where i^h without time index denotes the steady state gross safe rate, χ^i denotes the safe rate's persistence and $\epsilon_t^{h,i}$ is normally distributed, $\epsilon_t^{h,i} \sim N(0, \sigma^i)$.[53]

The ex ante risky rate in the model is defined as the expected gross return on the risky asset

$$\mathbb{E}_t\{r_{t+1}^h\} = \mathbb{E}_t\Big\{D_{t+1}^h \frac{(q_{t+1}^h + c^h)}{q_t^h}\Big\}. \tag{2.17}$$

[50] The coupons ensure that in steady state risky asset returns exceed the cost of debt, and hence the bank levers up to its VaR constraint.

[51] In order to keep the exposition simple, this formulation abstracts from the correlation of returns across assets.

[52] Adrian and Shin (2013) provide a microfoundation for VaR constraints in terms of a moral hazard problem between the bank and its creditors.

[53] Assuming the interest rate to be an exogenous process can favor the finding of extensive risk premium spillovers in the sense that the safe rate is assumed not to work against the spillover. Or, put differently, the existence of extensive risk premium spillovers is predisposed on their not provoking an offsetting monetary policy response. Prior to 2007 monetary policy was usually not targeting risky asset prices (see Fuhrer and Tootell, 2008).

The bad scenario realization of r_t^h is defined by $D^{h,low}$ and $q^{h,low}$: $r_t^{h,low} = D^{h,low} \frac{(q^{h,low}+c^h)}{q_t^h}$.

The default rate also follows an AR(1) process

$$D_t^h = (1-\chi^D)D^h + \chi^D D_{t-1}^h + \epsilon_t^{h,D}, \tag{2.18}$$

with persistence χ^D and $\epsilon_t^{h,D} \sim N(0,\sigma^D)$.[54]

The market clearing conditions are

$$b_t^{h\star} + b_t^h = b_S{}^h + \frac{1}{\psi} q_t^h \tag{2.19}$$

$$b_t^f + b_t^{f\star} = b_S{}^f + \frac{1}{\psi} q_t^f, \tag{2.20}$$

where b_S^h and b_S^f are exogenously fixed supplies of the risky H and F asset, respectively. ψ denotes the inverse demand elasticity of risky assets with respect to their price. When banks sell risky assets, this parameter determines how much asset prices fall before non-bank agents step in and stabilize asset prices.[55] Alternatively ψ can be interpreted as a supply elasticity which indicates by how much risky asset supply increases in the price of risky assets.

To focus on the international risk-taking channel I close the model with the foreign exchange market equation

$$e_t = 1 + \frac{1}{\phi}(ED_t^f), \tag{2.21}$$

where ED_t^f denotes the excess demand for foreign currency (see Branson and Henderson, 1985; Bruno and Shin, 2014).[56] Thus the exchange rate (home currency/foreign currency) is rising in the excess demand for foreign currency. This equation can be thought of as a stand-in for the balance of payment equation in a more fully fledged model of the world economy. It is supposed to complement the model's endogenous capital account dynamics with a current account counterpart. This is important because the resulting restriction on the exchange rate endows the model with plausible capital account dynamics. The parameter ψ can be interpreted as the current account's sensitivity with respect to the exchange rate, i.e. the trade elasticity.[57] The full set of non-linear model equations is summarized in appendix

[54] While the exogenous process for D_t is not bounded from below, in the calibration the innovation variance is small relative to its steady state, so that in the simulations D_t never becomes negative.

[55] These non-bank investors can be thought of as risk averse households who only step in once falling asset prices have increased expected returns sufficiently to compensate for the riskiness of the risky asset. Alternatively, Calvo (1998) provides an account in which leveraged investors that face margin calls need to liquidate their asset holdings and sell them to less informed counterparts. As a consequence of the resulting asymmetric information problem asset prices need to fall before less informed investors step in.

[56] ED^f is calculated as the capital flow residual resulting from subtracting all capital inflows from H into F from all capital outflows from H into F: $ED_t^f = \left(d_t^{h,\star} + e_t\, q_t^f\, b_t^f - d_t^f\, e_t - e_t\, D_t^f\, \left(q_t^f + c^f\right) b_{t-1}^f + e_t\, i_{t-1}^f\, d_{t-1}^f - q_t^h\, b_t^{h,\star} + D_t^h\, \left(q_t^h + c^h\right) b_{t-1}^{h,\star} - i_{t-1}^h\, d_{t-1}^{h,\star}\right)$.

[57] The foreign exchange market equation has also been used as a way to model foreign exchange market

2.A.1. For the subsequent analysis I linearize the model around it's nonstochastic steady state.

2.4.2. *International transmission of safe and risky rates*

What does the linearized model say about international co-movement in safe and risky interest rates? To gain intuition the following exposition assumes that the foreign portfolio adjustment costs are negligible, i.e. $\tau \to 0$. Uncovered interest rate parity (UIP) holds for safe rates up to a portfolio adjustment term:

$$\hat{i}_t^h = \hat{i}_t^f + \mathbb{E}_t\{\hat{e}_{t+1}\} - \hat{e}_t, \tag{2.22}$$

where the hat ($\hat{\ }$) denotes a variable's percentage deviation from steady state. A fixed exchange rate thus implies perfect co-movement among safe rates. By contrast, among floats, central banks are free to set safe rates according to their policy goals, and the nominal exchange rate will adjust to satisfy UIP-equation 2.22. In this way floating exchange rates provide effective insulation for safe rates and the trilemma holds.

How about risky rates? The non-arbitrage condition for risky rates is

$$\mathbb{E}_t\{\hat{r}_{t+1}^h\} = \mathbb{E}_t\{\hat{r}_{t+1}^f\} + \Omega(\mathbb{E}_t\{\hat{e}_{t+1}\} - \hat{e}_t) + (1-\Omega)(\hat{r}_t^{f,low} - \hat{r}_t^{h,low}), \tag{2.23}$$

where $\Omega \equiv \frac{i^h}{r^h}(1 + \frac{\lambda}{\beta\mu})$ and variables without time index denote steady state values. Unlike for safe rates, the exchange rate does not account for the entire risky rate differential across regions.

In the following calibration Ω is less than 1. In this case the second term in equation 2.23 indicates that expected exchange rate changes drive a smaller wedge between the home and foreign risky rate than they do between safe rates, thus contributing to risky rate co-movement among floats. The third term says that whenever the foreign-home spread in bad scenario returns goes up, the home risky return declines. The reason for this is that if foreign bad scenario risky returns are higher than home ones then asset demand shifts to the foreign risky asset.

Another perspective to look at this is through risk premiums. The risky rate equals safe rate plus risk premium (ρ_t): $r_t \equiv i_t + \rho_t$. To the extent that floating exchange rates decouple safe rates any co-movement in risky rates must come from risk premiums. The home risk premium's percentage deviations from its steady state can be expressed as:

$$\hat{\rho}_t^h = \hat{\lambda}_t(r^h - r^{h,low}) - \mathbb{E}_t\{\hat{\mu}_{t+1}\} + \Big(\frac{i^h}{i^h - r^h}\,\hat{i}_t^h - \frac{r^{h,low}}{i^h - r^h}\,\hat{r}_t^{h,low}\Big). \tag{2.24}$$

Equation 2.24 shows that the model gives rise to a risk premium that fluctuates endogenously with the development of three components: First, the marginal value of easing the VaR

imperfections that cause foreign exchange supply to be less than perfectly elastic. According to this interpretation a lower ψ indicates a larger imperfection, and hence a less elastic foreign exchange supply (see Hau and Rey, 2005).

constraint ($\hat{\lambda}_t$), times the differential between the safe rate and the bad scenario risky return, with $i^h > r^{h,low}$. Intuitively, the tighter the VaR constraint, the larger the spread between risky and safe rates from which the bank could profit if its VaR constraint was marginally eased. Second, the risk premium is decreasing in the expected tightness of next period's law of motion constraint for equity ($\mathbb{E}_t\{\hat{\mu}_{t+1}\}$). The more abundant bank equity is expected to be in the next period, the less likely it is that the bank has to engage in costly equity issuance, and hence that shareholders have to cut their consumption. Therefore the bank engages in more risk-taking today, which drives down the risk premium. Finally, the risk premium is also decreasing in the differential between the safe rate and the bad scenario risky rate.

A comparison of the home risk premium in equation 2.24 with the foreign risk premium reveals their similarity, and hence their scope for co-movement:

$$\hat{\rho}_t^f = \hat{\lambda}_t(r^h - r^{h,low}) - \mathbb{E}_t\{\hat{\mu}_{t+1}\} + \Big(\frac{i^f}{i^f - r^f}\,\hat{i}_t^f - \frac{r^{f,low}}{i^f - r^f}\,\hat{r}_t^{f,low}\Big), \tag{2.25}$$

where I make use of the steady state relations $r^f = r^h$ and $r^{f,low} = r^{h,low}$. The first and second terms in equation 2.25 are identical to the first and second terms in equation 2.24. The equalization of risk premiums – the price of risk – is not surprising, given that financial markets are integrated. However, the bank's leverage constraint can, through its effect on the risk premium, cause the risky rate to move in excess of safe rates. Any such excess movement in the risky rate will be transmitted internationally by the bank's arbitrage activity. The bank will buy the risky asset with the higher return and sell the risky asset with the lower return until the non-arbitrage condition 2.23 is satisfied. In equilibrium, this gives rise to risky rates co-movement.[58]

2.4.3. *Calibration*

In this section I calibrate the model in order to evaluate the its quantitative implication for the co-movement of risky rates among floats. The model is calibrated in such a way as to render the F region's relation to the H region reminiscent of the U.S.'s relation to the rest of the world (ROW). However, except for the steady-state gross foreign asset positions and the fixed endowments the home and foreign segments of the model are calibrated symmetrically. The model is calibrated to a monthly frequency.

The monthly time preference rate is set to an annualized 0.9967 (i.e. an annual 0.96 = 0.9967^{12}). This corresponds to the annualized safe rate's steady state, which is set to 4% – the long-time empirical average of short-term safe rates. The monthly persistence of the safe rate is set to 0.94. The standard deviation of the safe rate shock is calibrated to match the standard deviation of the monthly narrative monetary policy shock series by Romer and Romer (2004). In order to reflect the co-movement in safe rates documented in section 2.2.2 I also calibrate

[58]This risk premium spillover mechanism can bite even for low levels of cross-border asset holdings. Only in the case of perfect autarky, when each bank holds only domestic assets and liabilities, is this asset price channel shut down.

the home and foreign safe rate shocks to be correlated with a correlation coefficient equal to 0.4. This is intended to account for the level of late 20th century co-movement in fundamentals (see Bordo and Helbling, 2011) that induces correlated central bank responses, and hence correlated safe rates.

The parameter σ is gleaned from Kollmann, Enders and Müller (2011). In their banking model they set $\sigma = 1$. The value of 1 is on the lower end of the values that are conventionally chosen when parameterizing a representative household's utility function. Among the most important shareholders of global banks are investment funds, which presumably are less risk averse than the average household.

The low repayment rate parameter (D^{low}) was set to $0.97^{1/12}$, implying an annualized bad scenario default rate of 3%. This reflects the higher end of annual default rates for corporate bonds over the past few decades (see Standard & Poor's Global Fixed Income Research and Standard & Poor's CreditPro). For example, the global default rate on corporate bonds during the 2008 financial crisis was slightly above 4%, while the default rate after the 2001 stock market crash peaked at slightly below 4%. The value for the standard deviation of the default shock (0.0003) was gleaned from Kollmann, Enders and Müller (2011).[59]

I consider large U.S. investment banks and European universal banks to be the financial institutions closest corresponding to the marginal investors depicted in the model. I set the low asset price realization ($q^{h,low}$) to target their asset to capital ratio. Prior to 2007 the total (unweighted) asset to (book) equity ratios of these institutions were located in the 25 to 35 range (see Eichengreen, 1999). In the model, the asset side of the banks' balance sheets only depicts risky assets that are tradable. For big banks that manage a global portfolio such tradable securities make up about one quarter to one third of their balance sheet (He, Khang and Krishnamurthy, 2010; Baily, Bekker and Holmes, 2015). In order to bring the model to the data I thus target three times the pre-crisis asset to capital ratio of 30, i.e. a capital-asset ratio of 0.1. This can be thought of as effectively netting out non-traded safe assets and safe liabilities, which are of no explicit interest with respect to the channel discussed here. As a result of this, the impact of asset price variations on bank equity will be quantitatively realistic.

The risky bond coupon (c) is set to 0.005. Given the steady state price for the risky assets this implies a 5.5% per year coupon on the steady state value of the risky bond. This is a typical value located in the center of the range of empirically observable coupon rates for corporate bonds.

The inverse elasticity of risky asset demand (ψ) is set to 0.0265. This value implies an average 7.5% fall in ROW asset prices in response to a +1ppt innovation to the U.S. safe rate, less if the ROW's exchange rate is floating with respect to the U.S., more if the exchange rate is is fixed. This conforms to recent post-1980 empirical evidence by Jordà et al. (2017*b*) for the response of international equity prices to a +1ppt hike in the U.S. policy rate.[60]

[59] Also see delinquency rates on commercial and industrial loans since the late 1980s for similar numbers (FRED, DRBLACBS).

[60] Empirical estimates for the international impact of U.S. policy rate innovations within the day are lower, ranging from 2.7% to 5% (Ehrmann and Fratzscher, 2009; Laeven and Tong, 2012). The stronger

Table 2.6: *Calibration parameters*

Parameters		Value	Source/Target
i	SST safe rate	$1.04^{1/12}$	Longtime empirical average
β	Time preference rate	0.9967	$1/i$
σ	inverse IES	1	Kollmann, Enders and Müller (2011)
D^{low}	Low repayment rate	$0.97^{1/12}$	S & P Global Fixed Income Research
D	SST repayment rate	$0.985^{1/12}$	S & P Global Fixed Income Research
q^{low}	Low asset price	1	0.1 Bank capital-tradable assets ratio
c	Risky asset coupon	0.005	5.5% SST coupon
ψ	Inv. asset demand elast.	0.0265	H asset price response
τ	Portfolio adj. cost	0.0001	
ϕ	Inv. FX demand elast.	0.66	1.5 trade elasticity
b_S^h	H risky asset supply	36	Fin. Acc. of the U.S.; Lund et al. (2013)
b_S^F	F risky asset supply	64	—"—
o_d^f	H liabilities from F	4	—"—
o_d^h	F liabilities from H	1	—"—
o_b^f	H risky assets from F	5	—"—
o_b^h	F risky assets from H	5	—"—
y	H shareholder income	0.5	ROW income/U.S. income = 2
$y^\star$	F shareholder income	0.25	capital income/total income = 1/3
Exogenous processes			
χ^i	Safe rate persistence	0.94	
σ^i	S.D. policy shock	0.003	Romer and Romer (2004) shock S.D.
$corr$	Safe rate correlation	0.4	see empirical analysis (section 2.2.2)
χ^D	Default rate persistence	0.98	Kollmann, Enders and Müller (2011)
σ^D	S.D. default shock	0.0003	Kollmann, Enders and Müller (2011)

I set the marginal portfolio adjustment cost (τ) to 0.0001. Given steady state foreign safe asset holdings of 4 this implies that a 1% deviation from steady state drives only a $4 \cdot 10^{-5}$ ppt wedge between the home and foreign safe rates, rendering the portfolio adjustment term a technicality for the sole purpose of determining steady state foreign asset holdings.

The parameter governing the sensitivity of the exchange rate with respect to capital account imbalances (ϕ) is set to 0.66. This is consistent with standard estimates of the elasticity of international trade with respect to tradable goods' prices in current open economy macro models.

The parameters $o_d^f, o_d^h, o_b^f, o_b^h, b_S^h$ and b_S^f that describe global tradable asset supply and determine the steady state gross foreign asset positions are set in such a way as to render the F region's relation to the H region reminiscent of the U.S.'s relation to the rest of the world (ROW). For this purpose, I draw from the Financial Accounts of the U.S. together with estimates of the world total of tradable assets (Lund et al., 2013). I normalize the world total of tradable assets to 100. The fraction of U.S. tradable securities in the world total is 36. Correspondingly b_S^h is set to 36 while b_S^h is set to 64. Turning to steady state foreign liability

responses presented by Jordà et al. (2017*b*) refer to a longer horizon of several years. As the interest here is to sketch the international response to U.S. policy shocks over the course of several years my choice of ψ targets the 7.5% figure.

holdings, o_d^f is set to 4, while o_d^h is set to 1. This reflects the asymmetric importance of the USD liabilities in the global financial system. The low value of 1 for o_d^h furthermore takes into account that 70% of the liability side of the U.S. external portfolio is denominated in U.S. dollars (see Lane and Shambaugh, 2010; Bénétrix, Lane and Shambaugh, 2015). To obtain realistic valuation effects, I treat these liabilities as intra-U.S. liabilities in the current setup. Steady state foreign asset holdings (o_b^f and o_b^h) are set to 5 each. This corresponds to the U.S. holding 5/64 = 7.81% of ROW tradable assets, while the ROW holds 5/36 = 13.89% of U.S. tradable assets.

Finally, I set the fixed endowments y and $y^\star$ to 0.5 and 0.25. The U.S. value of 0.25 is set to target the capital income share of bank shareholders. The U.S. capital income share ranges from 0.25 to 0.34. Because the model is concerned with the fraction of the population that owns risky assets I chose a value at the higher end of that range, 0.3 (see Constantinides, Donaldson and Mehra, 2002). Taking into account that the model only depicts about one third of the typical marginal investor's balance sheet, I set $y^\star$ such as to yield a steady state dividend to income ratio of 0.1. The ROW value of 0.5 then follows from U.S. GDP being around one third of world GDP in the post Bretton Woods period.

2.4.4. Results

In order to link the model part of this paper back to its empirical part this section reports model outputs that correspond to the empirical results reported earlier: the decoupling power of floating exchange rates for safe and risky rates, as well as the differential response of pegs and floats to U.S. policy rate shocks.

Average global interest rate correlations and decoupling powers

First, consider the international correlation of safe and risky rates generated by the model. I run a stochastic simulation based on the linearized model to obtain international correlations for risky and safe rates depending on exchange rate regime status. Table 2.7 displays the result. Safe and risky rates perfectly co-move among pegs, resulting in a correlation of 1. For floats, interest rate co-movement differs whether one considers safe or risky rates. Safe rates' correlation is 0.40 due to the calibration matching fundamental safe rates' co-movement in the data. Risky rates' correlation on the other hand is 0.86.

Table 2.7: *Model correlations*

	(1) Safe rates	(2) Risky Rates
Pegs' correlation	1.00	1.00
Floats' correlation	0.40	0.86

Second, I calculate the decoupling power of a floating exchange rate on the basis of 10,000 simulations of the floater and peg model each. Each simulation is 480 months long, –40 years – i.e. comparable in length to the post-Bretton Woods sample. For comparability with the empirical results I aggregate the simulated series to an annual frequency and take first differences. I then combine the data obtained from the simulations and run regressions according to equation 2.5. On the basis of the resulting regression coefficients I then calculate the decoupling power ratio 2.6. Table 2.8 displays the results. For safe rates the model exhibits a close to 100% decoupling power for floating exchange rates. By contrast, for risky rates floating exchange rates have only a 52% decoupling power. The safe rate-risky rate dichotomy in the decoupling power of floating exchange rates in the model thus bears out the same dichotomy as the data.

Table 2.8: *Model decoupling powers*

	(1) Safe rates	(2) Risky Rates
Decoupling power	114%	52%
s.e.	(45)	(21)

Global response to U.S. monetary policy shocks

What does the calibrated model say about the response of floats' risky rates to a monetary policy shock in the financial center? I consider a +1 ppt innovation in the U.S. policy rate. I simulate the model twice, once with the ROW featuring a flexible exchange rate with respect to the USD, and once with a fixed exchange rate. In the fixed exchange rate model the ROW country's central banks sets its interest rate in such a way as to ensure a fixed nominal exchange rate.[61] The impact of a +1 ppt safe rate shock in the U.S. on international safe and risky rates for the peg and the float are depicted in figure 2.5. The peg's response is depicted as a solid black line, the float's response as a dashed blue line. For floats I further analyze the case of zero underlying correlation, where safe rates between the U.S. and the ROW do not co-move at all (dotted blue line).

For safe rates the distinction in exchange rate regime is clear: The peg fully imports the foreign interest rate increase (solid black line), the float on the other hand does not. In accordance with the calibration, the float's safe rate reflects only 40% of the U.S. +1 ppt hike. This is the degree of safe rate correlation observable in the data (dashed blue line). By construction, in the zero underlying correlation case the floating ROW safe rate does not respond at all.

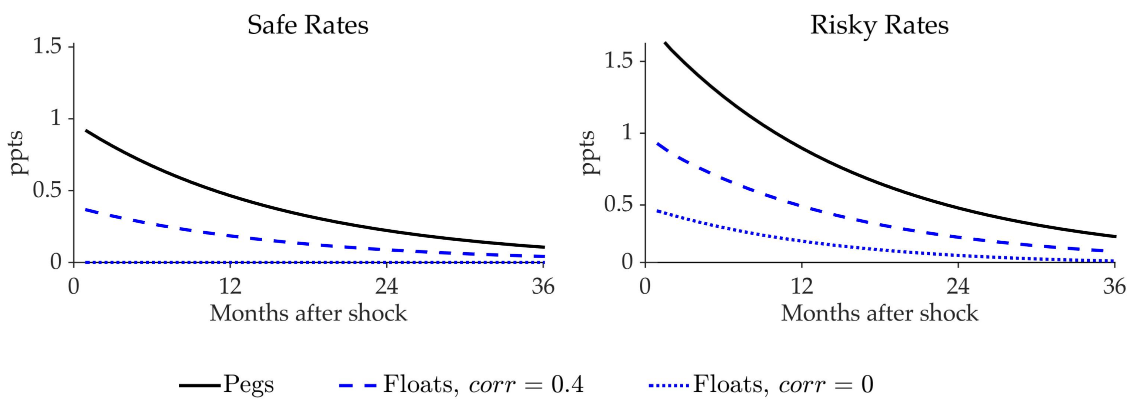
How about risky rates? Here the peg-float dichotomy starts to blur somewhat. The floating economy's risky rate clearly reacts to the innovation in the U.S. safe rate, with the float's risky rate increasing by close to 1 ppt (dashed blue line). The pegged home economy's risky rate reacts more than the float's risky rate (solid black line). On top of the full pass-through of the U.S. safe rate, the peg's risky rate also exhibits a risk premium spillover of about 0.5 ppts, a feature which was absent in the empirical impulse responses reported earlier.[62]

[61] The home interest rate rule satisfies $i_t^h = i_t^f + \tau(b_t^f - o_b^f)/e_t + 0.01(1/e_t - 1/\bar{e})$, where the last penalty term on exchange rate deviations implies exchange rate stabilization (see Benigno and Benigno, 2008)

[62] The interest rate responses obtained from the model are not hump-shaped as are their empirical

When the fundamental co-movement in safe rates is set to 0 the floats' response becomes weaker. The international risk-taking channel on its own, without any fundamental safe rate co-movement, can account for around 50% of the observed international risky rate response of floats (see dotted line in figure 2.5).[63]

Figure 2.5: *Pegs' and floats' response to a +1 ppt U.S. policy rate shock*



Notes: Solid black line – response of pegs; dashed blue line – response of floats with fundamental safe rate co-movement; dotted blue line – response of floats without fundamental safe rate co-movement.

To better understand the co-movement in risky rates figure 2.6 depicts various other impulse response functions that show the forces at work. First, the +1 ppt policy rate hike in the U.S. leads to a fall in risky asset prices, ranging from 5 to 10% (see Jordà et al., 2017*b*). As assets are marked to market, falling asset prices negatively impact bank equity. This is accompanied by an increasingly binding VaR constraint. Bank leverage, here defined as the ratio of total asset to equity, goes up on impact as the banks' shrinking asset side eats into their equity. Thereafter, however, banks' balance sheets start to recover over a prolonged phase of deleveraging.

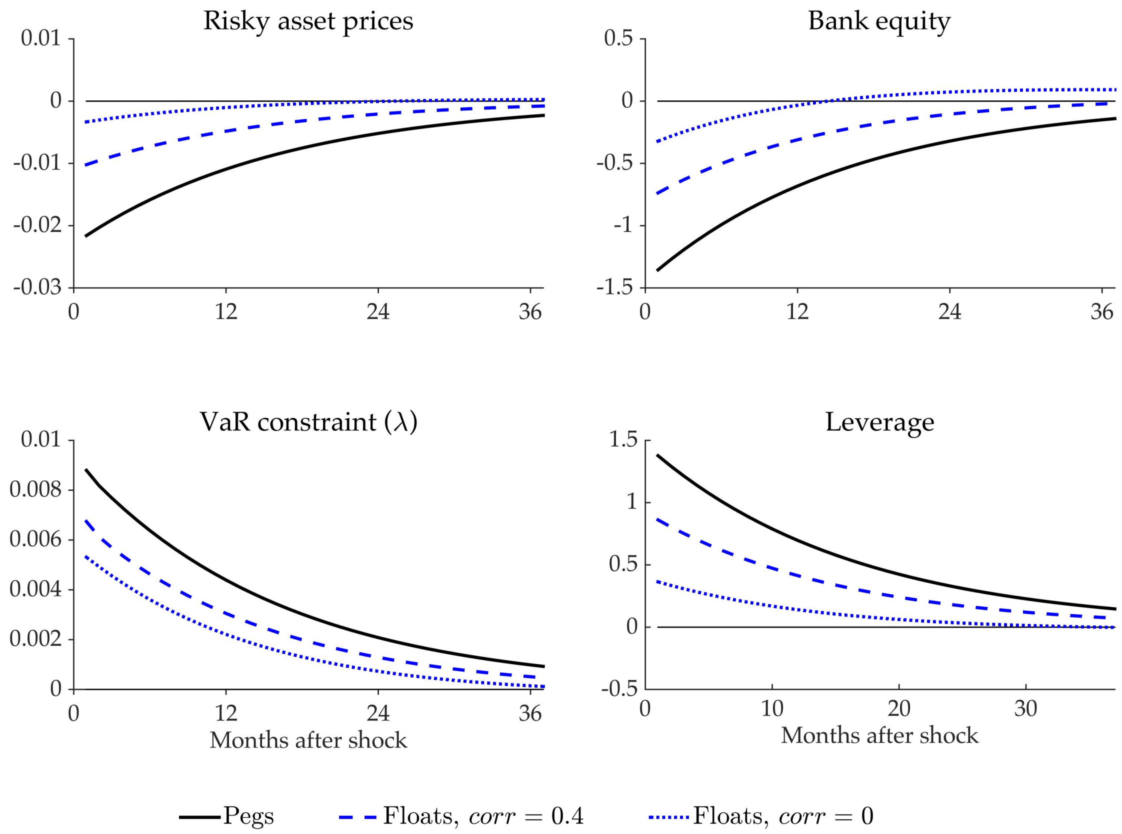
To get an impression of how much of the float's response is due to exchange rate valuation effects on intermediary balance sheets as described by Bruno and Shin (2015) I recalculate all impulse responses for the case in which the home bank perfectly hedges its foreign currency exposure, i.e. the value of its foreign currency denominated liabilities equals the value of its foreign currency denominated assets.[64] In particular I replace the banks' first order conditions with respect to the non-local liability with the hedging equation $b_t^f = q_t^f b_t^f$. Figure 2.8 in the

counterparts. In order to generate such an initially incomplete pass-through additional frictions would be necessary.

[63]The peg-float differential among safe rates is not necessarily the same as that among risky rates. The non-arbitrage condition for risky rates (equation 2.23) shows why. First, $\Omega < 1$ lowers the distance between the peg's and the float's risky rate response relative to the safe rate response. Second, the difference in the bad scenario returns of the home and foreign risky assets also plays a role.

[64]Banks tend to hedge against currency mismatch in their balance sheet (see McCauley and McGuire, 2014).

Figure 2.6: *Pegs' and floats' response to a +1 ppt rate shock*



Notes: Solid black line – response of pegs; dashed blue line – response of floats.

appendix shows that in this case the impulse responses are very similar.

In sum, given the co-movement in safe rates, the calibrated 2-region banking model generates a risky rate response for floats that is close to its empirical counterpart. Without the co-movement in safe rates, the proposed international risk-taking channel can account for around half of the observed peak response of floats' risky rates.

2.5. Conclusion

Extensive risk premium spillovers have rendered floating exchange rates relatively ineffective at decoupling local risky rates from their global counterparts. In this sense my results do support claims that the macroeconomic policy trilemma is morphing into a dilemma, according to which floating exchange rates have become increasingly impotent in countering international financial spillovers. However, this is a new phenomenon. Early in the 20th century floating exchange rates were still effective at insulating local risky rates from foreign ones.

I rationalize the increasing ineffectiveness of floating exchange rates with the growing importance of global banks as marginal investors in global asset markets. If financial globalization is based on leverage-constrained banks, mark-to-market of asset prices synchronizes risk-taking across borders, even among floats. Introducing an open economy model with financial intermediaries that manage an international portfolio of risky assets, I show that this international risk-taking channel can account for about 50% of the spillovers of U.S. monetary policy into the risky rates of floats.

The finding that floating exchange rates have become ineffective at decoupling local risky rates does not necessarily imply that floating exchange rates are not worth having. After all, a floating exchange rate provides economic policymakers with one more degree of freedom for achieving their policy goals. However, my findings suggest that the world economy has become a considerably more demanding environment for policymakers to operate in. The rise of financial spillovers can drive a wedge between conventional targets of monetary policy, such as output and employment gaps, and other policy goals, such as financial stability targets. This divergence in policy targets worsens the trade-offs involved in the application of existing policy instruments. Policymakers may find themselves in need of additions to their policy toolkit.

My findings are speak to current debates about how to robustify open economies against financial shocks from abroad (Rey, 2013; Passari and Rey, 2015). The finding that floating exchange rates were effective at decoupling risky rates in the early 20th century shows that risk premium spillovers are not an inevitable consequence of financial globalization. Hence, the implementation of capital controls – de facto financial deglobalization – is not the only way in which monetary authorities can reassert their control over local interest rates. Instead, my findings suggest that institutional reform, aimed at lightening the interaction between leverage-constraints and mark-to-market accounting, can help to reconcile capital mobility with monetary autonomy. In this regard, the institutions that underpinned financial globalization at the beginning of the 20th century are worth another look.

2.A. Appendix

2.A.1. Non-linear model equations

This section displays the complete set of non-linear model equations used in the simulations. $t+1$ variables indicate expected values. Foreign F region variables are denoted with a star superscript ($\star$). The home and foreign banks maximize the expected discounted utility stream of their shareholders subject to three constraints. First, the equity laws of motion

$$k_t = k_{t-1} + \Pi_t - c_t + y \tag{2.A.1}$$

$$k_t^\star = k_{t-1}^\star + \Pi_t^\star - c_t^\star + y^\star. \tag{2.A.2}$$

Second, the balance sheet identities

$$k_t + d_t^h + d_t^f e_t = q_t^h b_t^h - q_t^f b_t^f e_t \tag{2.A.3}$$

$$k_t^\star + d_t^{f\star} + d_t^{h\star}/e_t = q_t^f b_t^{f\star} + q_t^h b_t^{h\star}/e_t. \tag{2.A.4}$$

Third, the VaR constraints

$$VaR_{t+1} \leq k_t \tag{2.A.5}$$

$$VaR_{t+1}^\star \leq k_t^\star. \tag{2.A.6}$$

The home and foreign banks' value at risk (VaR) is defined as their low profit-realization state, where profits are defined as

$$\begin{aligned} \Pi_t = \hat{q}_t^h b_{t-1}^h + \hat{q}_t^f b_{t-1}^f e_t - i_{t-1}^h d_{t-1}^h - i_{t-1}^f d_{t-1}^f e_t \; - k_{t-1} \\ - \frac{\tau}{2}\left(d_{t-1}^f - o_d^f\right)^2 - \frac{\tau}{2}\left(b_{t-1}^f - o_b^f\right)^2 \end{aligned} \tag{2.A.7}$$

$$\begin{aligned} \Pi_t^\star = \hat{q}_t^f b_{t-1}^{f\star} + \hat{q}_t^h b_{t-1}^{h\star}/e_t - i_{t-1}^f d_{t-1}^{f\star} - i_{t-1}^h d_{t-1}^{h\star}/e_t \; - k_{t-1}^\star \\ - \frac{\tau}{2}\left(d_{t-1}^{h\star} - o_d^h\right)^2 - \frac{\tau}{2}\left(b_{t-1}^{h\star} - o_b^h\right)^2 \end{aligned} \tag{2.A.8}$$

Accordingly, the home and foreign banks' VaR is defined as

$$\begin{aligned} VaR_{t+1} = \hat{q}^{h,low} b_t^h + \hat{q}^{f,low} b_t^f e_{t+1} - i_t^h d_t^h - i_t^f d_t^f e_{t+1} - k_t \\ - \frac{\tau}{2}\left(d_t^f - o_d^f\right)^2 - \frac{\tau}{2}\left(b_t^f - o_b^f\right)^2 \end{aligned} \tag{2.A.9}$$

$$\begin{aligned} VaR_{t+1}^\star = \hat{q}^{f,low} b_t^{f\star} + \hat{q}^{h,low} b_t^{h\star}/e_{t+1} - i_t^f d_t^{f\star} - i_t^h d_t^{h\star}/e_{t+1} - k_t^\star \\ - \frac{\tau}{2}\left(d_t^{h\star} - o_d^h\right)^2 - \frac{\tau}{2}\left(b_t^{h\star} - o_b^h\right)^2 \end{aligned} \tag{2.A.10}$$

The home bank's first order conditions with respect to consumption (c), the safe home and foreign liabilities, the risky home and foreign assets and bank equity (k) are:

$$c_t^{-\sigma} = \mu_t \tag{2.A.11}$$

$$\alpha_t = i_t^h(\beta\mu_{t+1} + \lambda_t) \tag{2.A.12}$$

$$\alpha_t = i_t^f \frac{e_{t+1}}{e_t}(\beta\mu_{t+1} + \lambda_t) + \tau(d_t^f - o_d^f)(\beta\mu_{t+1} + \lambda_t)/e_t \tag{2.A.13}$$

$$D_{t+1}^h(q_{t+1}^h + c^h)\beta\mu_{t+1} - \alpha_t q_t^h + D^{h,low}(q^{h,low} + c^h)\lambda_t = 0 \tag{2.A.14}$$

$$\begin{aligned}\beta\mu_{t+1}D_{t+1}^f(q_{t+1}^f + c^f)e_{t+1} - \tau(b_t^f - o_b^f)\beta\mu_{t+1} - \alpha_t q_t^f e_t +\\ D^{f,low}(q^{f,low} + c^f)e_{t+1}\lambda_t - \tau(b_t^f - o_b^f)\lambda_t = 0\end{aligned} \tag{2.A.15}$$

$$\alpha_t = \beta\mu_{t+1} + \mu_t \tag{2.A.16}$$

Analoguously the first order conditions of the foreign bank read:

$$c_t^{\star-\sigma} = \mu_t^\star \tag{2.A.17}$$

$$\alpha_t^\star = i_t^{f\star}(\beta^\star\mu_{t+1}^\star + \lambda_t^\star) \tag{2.A.18}$$

$$\alpha_t^\star = i_t^h \frac{e_t}{e_{t+1}}(\beta\mu_{t+1}^\star + \lambda_t^\star) + \tau(d_t^h - o_d^h)(\beta\mu_{t+1}^\star + \lambda_t^\star)e_t \tag{2.A.19}$$

$$D_{t+1}^f(q_{t+1}^f + c^f)\beta\mu_{t+1}^\star - \alpha_t^\star q_t^f + D^{f,low}(q^{f,low} + c^f)\lambda_t^\star = 0 \tag{2.A.20}$$

$$\begin{aligned}\beta\mu_{t+1}^\star D_{t+1}^h(q_{t+1}^h + c^h)/e_{t+1} - \tau(b_t^h - o_b^h)\beta\mu_{t+1}^\star - \alpha_t^\star q_t^h/e_t +\\ D^{h,low}(q^{h,low} + c^h)/e_{t+1}\lambda_t^\star - \tau(b_t^h - o_b^h)\lambda_t^\star = 0\end{aligned} \tag{2.A.21}$$

$$\alpha_t^\star = \beta\mu_{t+1}^\star + \mu_t^\star \tag{2.A.22}$$

Market clearing for the home and foreign risky bonds is characterized by

$$b_t^{h,\star} + b_t^h = b_S{}^h + \frac{1}{\psi}\, q_t^h \tag{2.A.23}$$

$$b_t^f + b_t^{f,\star} = b_S{}^f + \frac{1}{\psi}\, q_t^f, \tag{2.A.24}$$

where ψ is the inverse demand elasticity for the risky assets.
The model is closed through the foreign exchange market equation

$$\begin{aligned}e_t = 1 + \frac{1}{\Phi}\,\Big(d_t^{h,\star} + e_t\, b_t^f\, q_t^f - d_t^f\, e_t - e_t\, D_t^f\, \left(c^f + q_t^f\right)\, b_{t-1}^f +\\ e_t\, i_{t-1}^f\, d_{t-1}^f - q_t^h\, b_t^{h,\star} + D_t^h\, \left(c^h + q_t^h\right)\, b_{t-1}^{h,\star} - i_{t-1}^h\, d_{t-1}^{h,\star}\Big)\,,\end{aligned} \tag{2.A.25}$$

and exogenous processes for the safe rates and default shocks:

$$i_t^h = \left(1 - \chi^i\right)\ i^h + i_{t-1}^h\, \chi^i + \epsilon_t^{h,i} \tag{2.A.26}$$

$$i_t^f = \left(1 - \chi^i\right)\ i^f + i_{t-1}^f\, \chi^i + \epsilon_t^{f,i} \tag{2.A.27}$$

$$D_t^h = \left(1 - \chi^D\right)\ D^h + \chi^D\, D_{t-1}^h + \epsilon_t^{h,D} \tag{2.A.28}$$

$$D_t^f = \left(1 - \chi^D\right)\ D^f + \chi^D\, D_{t-1}^f + \epsilon_t^{f,D}. \tag{2.A.29}$$

Finally, several auxiliary equations have been made use of, such as total bank assets:

$$A_t = e_t\, b_t^f\, q_t^f + q_t^h\, b_t^h \tag{2.A.30}$$

$$A_t^\star = \frac{q_t^h\, b_t^{h,\star}}{e_t} + q_t^f\, b_t^{f,\star} \tag{2.A.31}$$

Bank leverage is here defined as the ratio of total assets to equity:

$$l_t = \frac{A_t}{k_t} \tag{2.A.32}$$

$$l_t^\star = \frac{A_t^\star}{k_t^\star} \tag{2.A.33}$$

The risky rate analyzed is the expected total return on the risky asset:

$$r_t^h = \frac{D_t^h(q_{t+1}^h + c^h)}{q_t^h} \tag{2.A.34}$$

$$r_t^f = \frac{D_t^f(q_{t+1}^f + c^f)}{q_t^f} \tag{2.A.35}$$

2.A.2. *Additional results*

Table 2.9: *Risk premiums calculated with base country safe rates*

	Safe rates		*Risk premia*		
	Δi^{ST}	Δi^{LT}	$\Delta \rho^{\text{Mort}}$	$\Delta \rho^{\text{Bank}}$	$\Delta \rho^{\text{Corp}}$
β_1	0.013**	0.038**	0.358***	0.763***	0.571***
	(0.006)	(0.017)	(0.092)	(0.037)	(0.104)
N	271204	15252	7763	8104	1514
R^2	0.04	0.23	0.33	0.44	0.17

Notes: Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Pre-1914 (1874-1913), Interwar (1919-1938), Bretton Woods (1950-1972), Post-Bretton Woods (1973-2007). Sample excludes WW1 (1914-1918) and WW2 (1939-1945) periods, as well as outliers, defined as absolute interest rate movements in excess of 50 ppts. Standard errors in parentheses.

Table 2.10: *Good quality data*

	Safe rates		*Risky rates*		
	Δi^{ST}	Δi^{LT}	Δr^{Mort}	Δr^{Bank}	Δr^{Corp}
β_1	0.10**	0.59***	0.27***	0.38***	0.47***
	(0.05)	(0.04)	(0.07)	(0.07)	(0.11)
β_2 $(float)$	-0.09*	-0.57***	-0.21***	-0.07	0.05
	(0.05)	(0.05)	(0.07)	(0.08)	(0.11)
DCP	-88%	-96%	-79%	-19%	11%
	(7.87)	(3.15)	(15.20)	(18.55)	(25.88)
N	15257	5854	3997	2430	1067
R^2	0.42	0.31	0.32	0.28	0.40

Notes: The sample excludes Afghanistan, Angola, Benin, Burkina Faso, Burundi, Cambodia, Cape Verde, Central African Republic, Chad, Comoros, Democratic Republic of Congo, CÃť'te dâĂŹIvoire, Djibouti, El Salvador, Eritrea, Ethiopia, Fiji, The Gambia, Grenada, Guinea-Bissau, Haiti, Lao PeopleâĂŹs Democratic Republic, Liberia, Libya, Mali, Mauritania, Mozambique, Myanmar, Niger, Nigeria, Rwanda, Sierra Leone, Swaziland, Syria, Timor-Leste, Togo, Uganda, Yemen and Zambia. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair-period fixed effects. Periods: Pre-1914 (1874-1913), Interwar (1919-1938), Bretton Woods (1950-1972), Post-Bretton Woods (1973-2007). Sample excludes WW1 (1914-1918) and WW2 (1939-1945) periods, as well as outliers, defined as absolute interest rate movements in excess of 50 ppts. Standard errors in parentheses. Sample excludes outliers, defined as absolute interest rate movements in excess of 50 ppts. Independent variables: Δr_j same rate as dependent variable. Standard errors in parentheses.

Table 2.11: *Advanced economies*

	Safe rates		*Risky rates*		
	Δi^{ST}	Δi^{LT}	Δr^{Mort}	Δr^{Bank}	Δr^{Corp}
β_1	0.22***	0.60***	0.24***	0.34***	0.48***
	(0.06)	(0.05)	(0.07)	(0.09)	(0.11)
β_2 $(float)$	-0.12***	-0.56***	-0.03	-0.00	0.07
	(0.04)	(0.07)	(0.08)	(0.08)	(0.11)
DCP	-57%	-94%	-11%	-1%	15%
	(8.34)	(6.75)	(30.38)	(24.51)	(26.51)
N	6461	5130	3437	1901	1021
R^2	0.22	0.29	0.28	0.28	0.42

Notes: The advanced economies subsample consists of Australia, Austria, Belgium, Canada, Cyprus, the Czech Republic, Denkmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Iceland, Ireland, Israel, Italy, Japan, Lithuania, Latvia, Luxembourg, Macao, Malta, the Netherlands, New Zealand, Norway, Puerto Rico, Portugal, Singapore, San Marino, the Slovak Republic, Slovenia, South Korea, Spain, Sweden, Switzerland, Taiwan, the U.K. and the U.S.A.. DCP – decoupling power of floating exchange rates. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Post-Bretton Woods (1973-2008, excludes zero lower bound period among advaced economies). Sample excludes outliers, defined as absolute interest rate movements in excess of 50 ppts. Standard errors in parentheses.

Table 2.12: *Emerging markets*

	Safe rates		*Risky rates*	
	Δi^{ST}	Δi^{LT}	Δr^{Mort}	Δr^{Bank}
β_1	0.11**	0.27*	0.08	0.09
	(0.05)	(0.15)	(0.19)	(0.23)
β_2 $(float)$	-0.10**	-0.17	-0.07	-0.05
	(0.05)	(0.10)	(0.18)	(0.23)
DCP	-97%	-63%	-90%	-53%
	(10.04)	(5.93)	(24.60)	(127.72)
N	10552	970	748	667
R^2	0.32	0.76	0.29	0.28

Notes: The emerging markets subsample consists of the full sample (see table 2.16) excluding the advanced country-sample (see table 2.11) and the low data quality sample (see table 2.10). DCP – decoupling power of floating exchange rates. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Post-Bretton Woods (1973-2015). Sample excludes outliers, defined as absolute interest rate movements in excess of 50 ppts. Standard errors in parentheses.

Table 2.13: *Post-1973 results for pre-1914 sample*

	Safe rates		*Risky rates*		
	Δi^{ST}	Δi^{LT}	Δr^{Mort}	Δr^{Bank}	Δr^{Corp}
β_1	0.48***	0.81***	0.25	0.32**	0.75***
	(0.10)	(0.05)	(0.22)	(0.15)	(0.11)
β_2 $(float)$	-0.15	-0.33***	0.12	0.10	-0.15
	(0.09)	(0.08)	(0.16)	(0.10)	(0.10)
DCP	-31%	-41%	49%	31%	-20%
	(14.96)	(8.39)	(106.89)	(46.19)	(11.52)
N	618	601	594	594	249
R^2	0.26	0.48	0.37	0.31	0.48

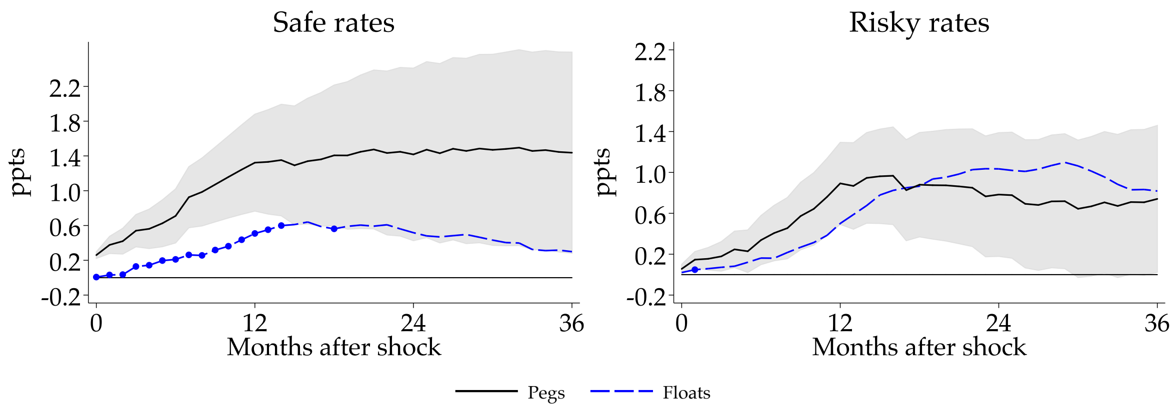
Notes: The countries from the pre-1914 sample are Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, U.K. and the U.S.. DCP – decoupling power of floating exchange rates. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Sample period: Post-Bretton Woods (1973-2007). Sample excludes outliers, defined as absolute interest rate movements in excess of 50 ppts. Standard errors in parentheses.

Table 2.14: *2-year changes*

	Safe rates		*Risky rates*		
	Δi^{ST}	Δi^{LT}	Δr^{Mort}	Δr^{Bank}	Δr^{Corp}
β_1	0.18***	0.62***	0.44***	0.36***	0.51***
	(0.05)	(0.04)	(0.08)	(0.09)	(0.09)
β_2 $(float)$	-0.17***	-0.26***	-0.24***	-0.02	-0.03
	(0.04)	(0.10)	(0.07)	(0.07)	(0.10)
DCP	-91%	-41%	-55%	-6%	-5%
	(5.07)	(15.09)	(15.15)	(18.90)	(18.24)
N	14347	5080	3361	1990	952
R^2	0.37	0.48	0.36	0.34	0.45

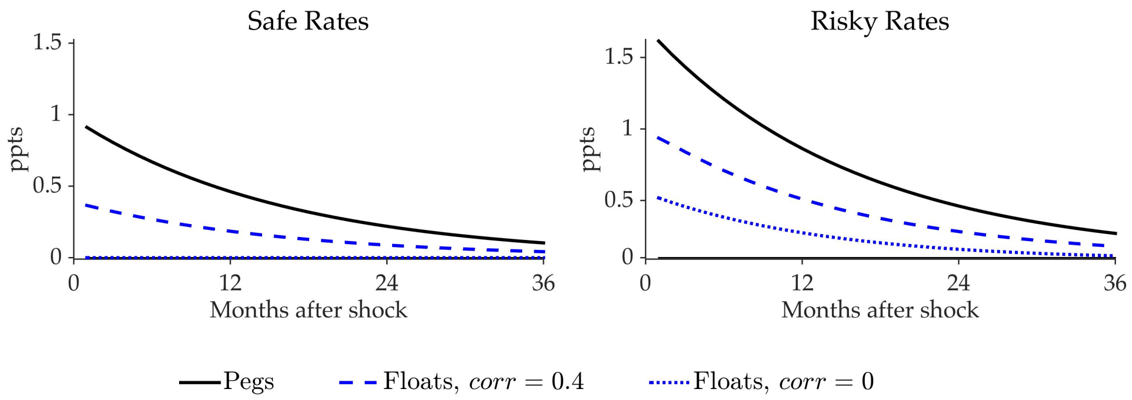
Notes: Regressions are based on 2-year interest rate changes. DCP – decoupling power of floating exchange rates. Driscoll-Kraay standard errors in parentheses (accounting for 3 lags of autocorrelation). All specifications include country-pair fixed effects. Periods: Pre-1914 (1874-1913), Interwar (1925-1938), Bretton Woods (1950-1969), Post-Bretton Woods (1974-2015). Sample excludes WW1 (1914-1918) and WW2 (1939-1945) periods, as well as outliers, defined as absolute interest rate movements in excess of 50 ppts. Standard errors in parentheses.

Figure 2.7: *Advanced economies, post-1973*



Notes: The advanced economies subsample consists of Australia, Austria, Bahrain, Bahamas, Belgium, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Iceland, Ireland, Israel, Italy, Japan, Kuwait, Latvia, Lithuania, Luxembourg, Macau, Malta, Netherlands, New Zealand, Norway, Portugal, Puerto Rico, Qatar, San Marino, Singapore, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, Taiwan, U.K. and the U.S.. Solid black line – response of pegs; dashed blue line – response of floats; Blue circles indicate the rejection of the null hypothesis that the peg response equals the float response at the 90% significance level, according to a two-sided Wald test. Confidence bands calculated on the basis of Driscoll-Kraay standard errors (accounting for 36 monthly lags of autocorrelation). All specifications include country fixed effects. Post-Bretton Woods sample: 1973:1 to 2010:12.

Figure 2.8: *Pegs' and floats' response to a +1 ppt U.S. policy rate shock, no exchange rate valuation effect*



Notes: Solid black line – response of pegs; dashed blue line – response of floats with fundamental safe rate co-movement; dotted blue line – response of floats without fundamental safe rate co-movement.

2.A.3. Data

Table 2.15: *Annual pre-1945 sample*

Australia, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, UK, Italy, Japan, Netherlands, Norway, Portugal, Sweden, USA,

Table 2.16: *Annual post-1945 sample*

Afghanistan, Angola, Albania, Netherlands Antilles, United Arab Emirates, Argentina, Armenia, Antigua and Barbuda, Australia, Austria, Azerbaijan, Burundi, Belgium, Benin, Burkina Faso, Bangladesh, Bulgaria, Bahrain, Bahamas, Bosnia and Herzegovina, Belarus, Belize, Bolivia, Brazil, Barbados, Brunei Darussalam, Bhutan, Botswana, Central African Republic, Canada, Switzerland, Chile, China, Cote D'Ivoire, Cameroon, DR Congo, Congo, Colombia, Comoros, Cape Verde, Costa Rica, Cyprus, Czech Republic, Germany, Djibouti, Dominica, Denmark, Dominican Republic, Algeria, Egypt, Spain, Estonia, Ethiopia, Finland, Fiji, France, Micronesia, Gabon, UK, Georgia, Ghana, Guinea, Gambia, Guinea-Bissau, Equatorial Guinea, Greece, Grenada, Guatemala, Guyana, Hong Kong, Honduras, Croatia, Haiti, Hungary, Indonesia, India, Ireland, Iran, Iraq, Iceland, Israel, Italy, Jamaica, Jordan, Japan, Kazakhstan, Kenya, Kyrgyzstan, Saint Kitts and Nevis, Korea, Kuwait, Lao, Lebanon, Liberia, Libya, Saint Lucia, Sri Lanka, Lesotho, Lithuania, Luxembourg, Latvia, Morocco, Moldova, Madagaskar, Maldives, Mexico, Macedonia, Mali, Malta, Myanmar, Mongolia, Mozambique, Mauritania, Mauritius, Malawi, Malaysia, Namibia, Niger, Nigeria, Nicaragua, Netherlands, Norway, Nepal, New Zealand, Oman, Pakistan, Panama, Peru, Philippines, Papua New Guinea, Poland, Portugal, Paraguay, Qatar, Romania, Russia, Rwanda, Saudi Arabia, Senegal, Singapore, Solomon Islands, Sierra Leone, El Salvador, San Marino, Sao Tome and Principe, Suriname, Slovak Republic, Slovenia, Sweden, Swaziland, Seychelles, Chad, Togo, Thailand, Tajikistan, Tonga, Trinidad and Tobago, Tunisia, Turkey, Tanzania, Uganda, Ukraine, Uruguay, USA, Vanuatu, Saint Vincent and Grenadines, Venezuela, Vietnam, Samoa, Yemen, South Africa, Zambia, Zimbabwe,

Table 2.17: *Monthly pre-1914 sample*

Denmark, Spain, Japan, Portugal, Sweden,

Table 2.18: *Monthly post-1973 sample*

United Arab Emirates, Australia, Austria, Belgium, Bangladesh, Bulgaria, Bahrain, Bahamas, Brazil, Canada, Switzerland, Chile, China, Colombia, Czech Republic, Germany, Denmark, Ecuador, Egypt, Spain, Finland, France, UK, Greece, Hong Kong, Hungary, Indonesia, India, Ireland, Iceland, Israel, Italy, Jordan, Japan, Korea, Kuwait, Lebanon, Latvia, Macao, Mexico, Malta, Malaysia, Netherlands, Norway, New Zealand, Pakistan, Peru, Philippines, Poland, Puerto Rico, Portugal, Romania, Russia, Saudi Arabia, Singapore, San Marino, Slovak Republic, Slovenia, Sweden, Thailand, Turkey, Taiwan, Ukraine, Venezuela, Vietnam, South Africa,

Chapter 3

Global financial cycles and risk premiums

Joint with Òscar Jordà, Moritz Schularick and Alan M. Taylor

3.1. Introduction

The Global Financial Crisis highlighted the need for an evolution in macroeconomic thinking. In the past 40 years, the advanced world has become exponentially more leveraged. This "financial hockey stick" had profound implications for the business cycle. Òscar Jordà, Moritz Schularick and Alan M Taylor (2016) showed that business cycle correlations are far from universal cosmological constants. Rather, their evolution appears to be tightly linked with the growth of credit relative to GDP. Added to the urgency to integrate finance into the basic architecture of business cycle models, one could add that there is a more fundamental need to understand the financial cycle and its interplay with the business cycle.

The first goal of this paper is to fill some of these gaps by analyzing global financial cycles over the past 150 years across a sample of 17 advanced economies. While the comovement of real variables has been extensively studied in the literature, financial cycles have received less attention. This is partly due to the fact that long-run data for credit growth, house prices and equity prices have only recently become available (Òscar Jordà, Moritz Schularick and Alan M Taylor, 2016; Òscar Jordà, Katharina Knoll, Dmitry Kuvshinov, Moritz Schularick and Alan M. Taylor, 2017*a*).

Our analysis reveals that synchronization of financial cycles across countries has become increasingly prevalent. We can now speak of a global financial cycle whose effects are felt widely and more vividly over the past few decades than ever before. For the most part, financial synchronization has increased hand in hand with international synchronization of real variables, such as GDP, consumption and investment. Equity price synchronization follows a different pattern, however. We find a much more rapid increase in global synchronicity since the 1990s. Moreover, we find that this rise in equity price synchronicity exceeds that of dividends, whose international comovement is more in line with the comovement of cycles in real variables. The explanation for this divergence is the striking rise in the volatility and global covariation of equity return premiums, or risk premiums. Our analysis thus lends support to accounts that put asset prices and risk premiums at center stage in explaining the synchronization of the global economy (Dumas, Harvey and Ruiz, 2003; Fostel and Geanakoplos, 2008; Devereux and Yetman, 2010; Dedola and Lombardo, 2012; Ward, 2018).[1]

The second goal of this paper is to analyze the role that monetary policy plays in explaining the increased synchronization of global risk appetite. In particular, we find that U.S. monetary policy is a powerful driver of global risk appetite and thus binds together global equity prices. Moreover, we show that this synchronization of international risk taking is a new phenomenon. In the first era of globalization, before 1914, we do not find evidence linking risk appetite internationally. Possible explanations include current monetary practice and a more prominent role of leveraged financial intermediaries in the world economy today.

Links between our findings and the existing literature are numerous. First, we add a longer-run cross-country perspective to the existing financial cycle literature, such as Claessens, Kose and Terrones (2011), Drehmann, Borio and Tsatsaronis (2012) as well as Aikman, Haldane and Nelson (2014) and Schüler, Hiebert and Peltonen (2015). Second, we confirm recent research regarding the increase in global financial synchronization over the past two decades (e.g. Bruno and Shin, 2013; Cerutti, Claessens and Ratnovski, 2014; Obstfeld, 2014). Our data provide evidence in support of this trend towards increased financial synchronization. Third, we extend the literature that studies the relation between financial– and real–cycle comovements (see Metiu and Meller, 2015). Fourth, our work builds on an emerging literature that investigates the nexus between monetary policy and risk taking, asset prices, and global financial synchronization (Miranda-Agrippino and Rey, 2015).

The remainder of this paper is organized as follows. Section 3.2 briefly introduces our data and documents common long-run trend towards higher real and financial cycle synchronization. Section 3.3 digs deeper into the source of synchronization in equity markets and shows that the sharp increase in the comovement of the global equity return premium explains most of the comovement in international stock returns. Section 3.4 contains the core empirical part of the paper. It addresses the question of whether financial center monetary policy is a common driver of global equity return premiums. More specifically, we study how global equity markets react to changes in U.S. interest rates since WW2, and compare the results to previous periods. In Section 3.5 we evaluate the robustness of our results by using instrumental variable methods on the unexpected component of rate changes, as proxied by Gertler and Karadi (2015) high frequency shocks.

A natural international transmission channel is via exchange rates and hence we evaluate whether our findings on synchronicity are stronger for countries with fixed exchange regimes relative to countries that allow their exchange rate to float freely (see section 3.4.4). We find some evidence that the transmission effects are stronger for fixed exchange rate regimes, but they are still sizable for floaters. This finding adds an important new dimension to the debate

[1]Dumas, Harvey and Ruiz (2003) explain the excessive correlation of equity prices over fundamentals through the excessive volatility of a common stochastic discount factor.

about the degree to which international financial integration undermines monetary policy autonomy. In the case of equity markets, there is suggestive evidence that monetary policy in the center country triggers swings in risk appetite that appear to be independent of domestic monetary conditions.

The paper concludes by first providing an extensive discussion of our results in the context of recent literature in Section 3.6, followed by the conclusion. Numerous other robustness checks are included in an extensive appendix.

3.2. Financial and real cycle synchronization, 1870-2013

3.2.1. Data

The data that we use in this paper come from a number of sources. GDP, consumption and investment data come from the latest vintage of the Jordà, Schularick and Taylor (2016) Macrohistory Database (available at `www.macrohistory.net/data`). The dataset comprises annual data from 1870 to 2013, for 17 countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, U.K. and the U.S.. Combined, these 17 countries make up more than 50% of world GDP throughout the period we are looking at.

Financial cycles are associated with the synchronized ebb and flow in credit aggregates, house prices and equity prices across countries (see Claessens, Kose and Terrones, 2011; Drehmann, Borio and Tsatsaronis, 2012; Aikman, Haldane and Nelson, 2014). The credit series cover loans of all monetary financial institutions—including savings banks, postal banks, credit unions, mortgage associations and building associations—to the non-financial private sector.

To study equity- and house-price comovements we rely on the newly collected dividend and rental yield series introduced by Jordà et al. (2017*a*). The equity premium is defined as the excess total return of equity over long-term government bonds. Detailed explanation on how these data were constructed are available in that paper.

3.2.2. Methods

In order to analyze the international comovement of real and financial cycles we calculate 15-year rolling-window Spearman rank correlation coefficients. One reason to use this measure of correlation instead of the more traditional Pearson correlation is to capture monotone but not necessarily linear relationships. The appendix reports results based on rolling-window Pearson correlation coefficients, which turn our to be qualitatively similar. The 15-year rolling-windows that we use are backward-looking, that is, the correlation coefficient reported for 2000 is based on data from 1986 to 2000. Hence, we denote the Spearman correlation coefficient between countries i and j calculated over the 15-year window ending at time t as $s_t^{i,j}$ for $i, j = 1, \dots n$, n being the cross-sectional sample size. A global measure of association can then be constructed as the average of these bilateral correlations as follows:

$$\bar{s}_t = \frac{\sum_i \sum_{j<i} s_t^{i,j}}{N}; \qquad N = \frac{(n-1)n}{2}. \tag{3.1}$$

In terms of notation, t is the rolling-window time index defined earlier, $\bar{s}_t$ is the average bilateral correlation coefficient at t and $s_t^{i,j}$ is the bilateral correlation coefficient for country-pair i, j. The number of distinct correlations excluding the correlation of one country with itself is given by the usual formula $n(n-1)/2$ where n is the total number of countries in the sample. In order to account for the cross-sectional and temporal dependencies, all confidence intervals are constructed using a cross-sectional block-bootstrap procedure (see Kapetanios, 2008).

As a robustness check, we also construct a GDP-weighted average version of expression (3.1). In particular, we use the relative purchasing power-adjusted real GDP of the bilateral country pair i, j, that is:

$$\bar{s}_t^{\omega} = \sum_i \sum_{j<i} \omega_{i,j,t}\, s_t^{i,j} \qquad \text{with} \tag{3.2}$$
$$\omega_{i,j,t} = \frac{(GDP_{i,t} + GDP_{j,t})}{\sum_i \sum_{j<i}(GDP_{i,t} + GDP_{j,t})};$$

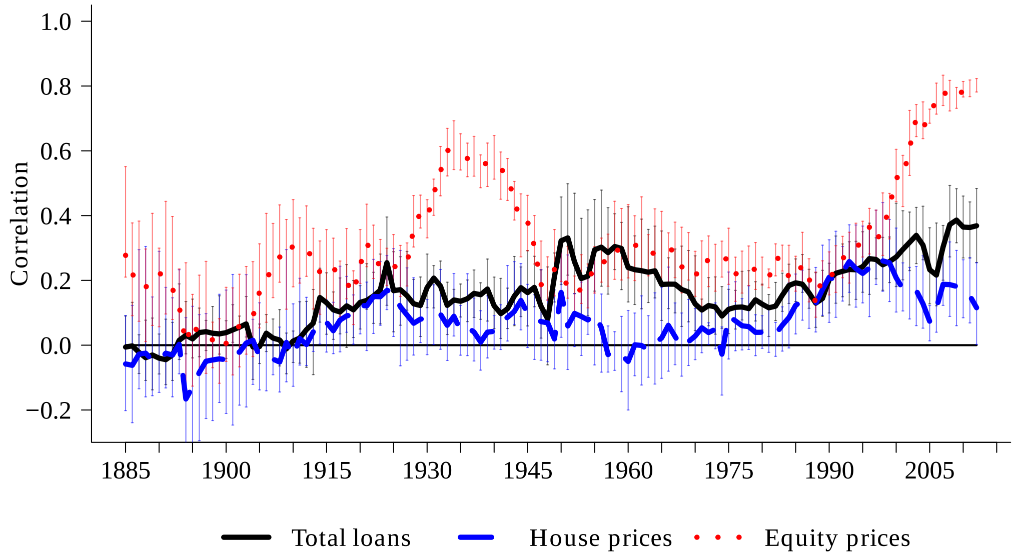
where $GDP_{i,t}$ denotes country i's GDP at time t. Results based on this GDP-weighted measure are generally very similar to those based on the unweighted measure described in expression (3.1) and are therefore reported in the appendix.

Next, note that to isolate the cyclical component in the series of our database we rely on the Baxter-King band-pass filter.[2] Financial cycles are typically characterized by relatively low frequency movements, with one cycle lasting between 8 to 16 years according to Drehmann, Borio and Tsatsaronis (2012), while Schüler, Hiebert and Peltonen (2015) find important variation in credit cycles well above the 20 year periodicity. Results by Cagliarini and Price (2017) in contrast suggest that financial cycles are not necessarily longer than business cycles. Also, equity prices, which we are also of interest here, exhibit important short-term variation. As a way to accommodate these divergent views, we take a conservative approach and therefore focus on a broad cycle-band ranging from 2 to 32 years. Before detrending, we CPI-deflate each series and take its logarithm.

As a robustness check, we also report results based on an alternative nonparametric detrending method recently suggested by Hamilton (2016). This approach relies on the observation that, unlike short-lived cyclical fluctuations, trend components are the only feature of the data that can be forecasted at longer horizons. Yet another approach is to put more weight on high-frequency annual changes. This has the advantage of not having to rely on a pre-processing filtering step. Hence, we study annual growth rates (total loans, house prices,

[2]In the subsequent correlation analysis we detrend all series with the exception of interest rates and equity return premiums, which are stationary in the long run.

Figure 3.1: *Average bilateral financial cycle correlation*



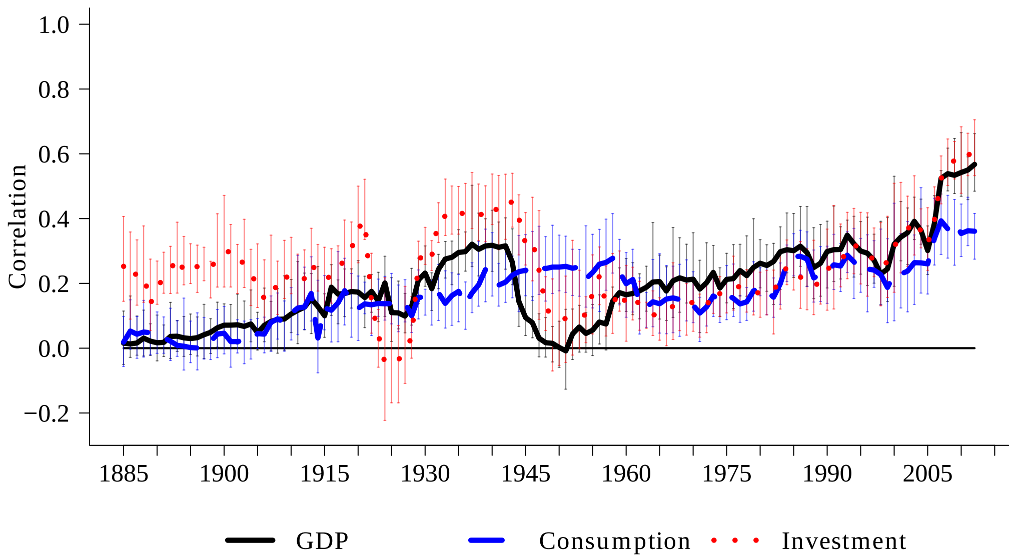
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

credit prices, GDP, consumption, investment, dividends) and first differences (real short-term rates, equity return premiums). Finally, we calculate concordance indices as proposed by Harding and Pagan (2002) in order to address concerns about heteroskedasticity bias in correlation coefficients (see Forbes and Rigobon, 2002). The concordance measure indicates the fraction of years in which two series move into the same direction. It abstracts from the size of such movements, rendering it immune to heteroskedasticity bias. Importantly, the core findings of the paper do not depend on the filtering method used. The appendix contains results using these alternative approaches for completeness.

3.2.3. Financial and real synchronization

This section presents the 15-year rolling window correlation results for the financial and real variables that have been introduced in data section 3.2.1. All variables have been detrended as described in section 3.2.2. Figure 1 displays the average bilateral correlation of three financial variables – real credit, real house prices and real equity prices—for the 17 country sample. Comovement in credit- and equity price-cycles has risen substantially over time. In particular, the comovement of credit and equity markets is at a historical peak today, with Spearman correlation coefficients of about 0.4 and 0.8 respectively. Abstracting from the bouts of house price comovement associated with WW1 and WW2 housing busts, international house prices are also more correlated today than before, but the divergence in global house prices since the financial crisis has dampened synchronization in recent years. The rise in equity price correlation to near unity since the 1990s is particularly striking as it exceeds even the correlation in asset prices during the declines associated with the Great Depression. The comovement

Figure 3.2: *Average bilateral real economy correlation*



Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series Bars – 95% cross-sectionally block-bootstrapped confidence bands.

in credit, house prices and equity prices is higher in the past few decades than in previous periods. But how does this compare to the long-run synchronization of real cycles in GDP, consumption and investment?

Figure 2 shows that the comovement of cycles in real variables also exhibits an upward trend since the start of the sample. The cyclical behavior GDP across countries is a good example—even accounting for the blip up due to the Great Depression (see Bordo and Helbling, 2003). GDP today exhibits an average bilateral correlation of somewhat above 0.5, its highest value since 1870. Similarly consumption correlation has trended upward nearly on a par with GDP, although today it is slightly lower than the correlation for GDP (see Backus, Kehoe and Kydland, 1992). The international comovement of investment had already been relatively high in the late 19th and early 20th centuries, but by the 2000s the comovement in investment reached a new peak.

International synchronization of the financial and real sectors of economies have increased in tandem. At some level this is to be expected. Globalization forces would tend to increase integration in the real economy and with it, the financial sector. However, as Figures 3.1 and 3.2 illustrate, it looks as if the comovement in equity prices has outstripped the comovement in other variables. This finding is robust to different detrending methods, as well as other synchronization measures (see figures 3.24 to 3.51 in the appendix).

Within our sample, some geographical regions exhibit more real and financial synchronization than others (see Figures 3.52 to 3.55 in the appendix). Within the euro area and within Scandinavia for example, GDP, consumption and investment have reached average bilateral correlation levels close to 0.8 over the past decades. In the case of Scandinavia, dividend comovement can explain more of the late 20th century increase in equity price correlation than it can in other regions. Finally, even within the Pacific region (Australia, Canada, Japan and the U.S.) equity price correlation has increased to around 0.7 since the late 20th century, despite virtually zero correlation in dividends.

Summing up, we document a substantial increase in the comovement of equity prices that is only partly matched by increasing real sector linkages. In the following sections, we will take a closer look at the drivers of the rising comovement in international equity markets.

3.3. Understanding equity market comovements

3.3.1. Correlation in dividends, risk-free rates and return premiums

How can the recent and dramatic increase in the comovement of international equity prices be understood? To get a first impression of the sources the lie behind the recent and dramatic increase in the comovement of international equity prices this section describes the international comovement of dividends, risk-free rates and equity return premiums. Figures 3.3 and 3.4 display the results. These figures show, first in Figure 3.3, the short-term and long-term risk-free rates, R. Figure 3.4 instead displays the average bilateral correlation between dividends, D, and the equity return premium, ERP.

Figure 3.3 shows that the average bilateral correlation in short- and long-term interest rates follow a similar time path. Interest rate correlation has been high in the 1980s and 2000s, and relatively low in the 1990s. Interest rate correlation was also high in the 1920s and 1930s. With the exception of the 1970s and 1980s, phases of high interest rate comovement thus tend to accompany phases of high equity price comovement. However, in contrast to equity price comovement after 1990, interest rate comovement has not reached historically unprecedented levels.

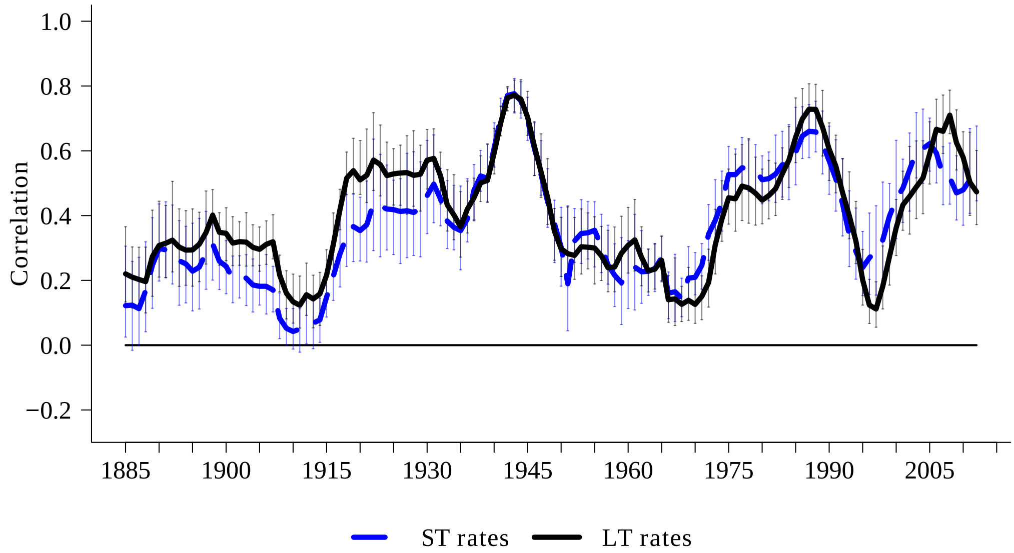
Figure 3.4 shows that the increases in equity price comovement in the 1920s and the 2000s were also accompanied by a significant increase in the comovement of dividends and equity return premiums. The comovement of dividends has peaked around 0.3 in the 2000s, coming close to its 1930s peak. The international correlation of equity return premiums, however, has reached historically unprecedented levels, rising from around 0.3 to 0.8.

These results suggest that the rising comovement of equity return premiums, ERP, seems to hold the key to understanding today's strong equity price synchronization. Various robustness checks, shown in the appendix, suggest that the finding that the comovement in equity return premiums has reached a historically unprecedented high is robust to different detrending methods (see figures 3.26 to 3.51 in the appendix).

3.3.2. Equity price comovement and risk appetite

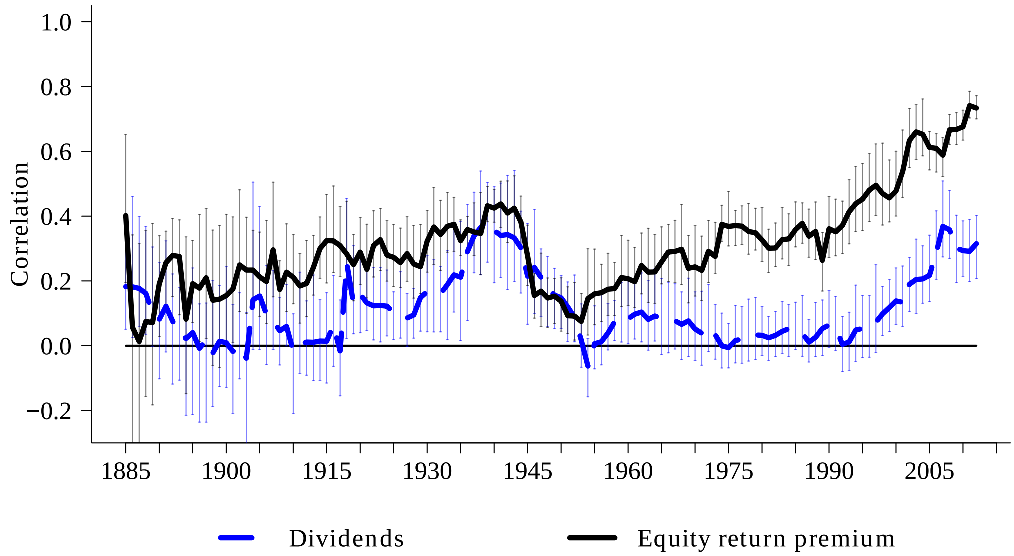
Next, we go one step further, in trying to understand to which extend co-movement in dividends and risk-free rates can explain comovement in equity prices. According to standard

Figure 3.3: *Average bilateral interest rate correlations*



Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Based on real interest rates, calculated as nominal rates minus CPI-inflation. Bars – 95% cross-sectionally block-bootstrapped confidence bands. *ST* refers to real short-term and *LT* to real long-term rates respectively.

Figure 3.4: *Average bilateral dividend and equity return premium correlations*



Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Dividends: 2 to 32-year period Baxter-King detrended series. Equity return premium: total equity returns minus short-term risk-free rate. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

asset pricing theory equity prices are a function of future dividend streams, discounted by a discount factor. Let Q^{RN} be the asset price as counterfactually valued by a risk-neutral investor who prices an asset according to the present value of future dividends D discounted by risk-free rates $R = 1 + r$:

$$Q_t^{RN} = E_t \left\{ \sum_{k=1}^{\infty} \left(\prod_{j=1}^{k-1} R_{t+j}^{-1} \right) D_{t+k} \right\}. \tag{3.1}$$

Furthermore, denote the remaining spread between actual asset prices Q_t and the counterfactual risk-neutral investor's price Q^{RN} as ρ:

$$Q_t = Q_t^{RN} \rho_t. \tag{3.2}$$

In the following analysis, we will call the term ρ "risk appetite". Of course "risk appetite" thus defined is a summary term, that encompasses all factors that drive a spread between discounted dividends Q^{RN} and actual equity prices Q. As such, the term "risk appetite" as we use it in the following embodies a diverse range of forces, such as consumption habits, the ability of intermediaries to supply loans as well as investor sentiment.

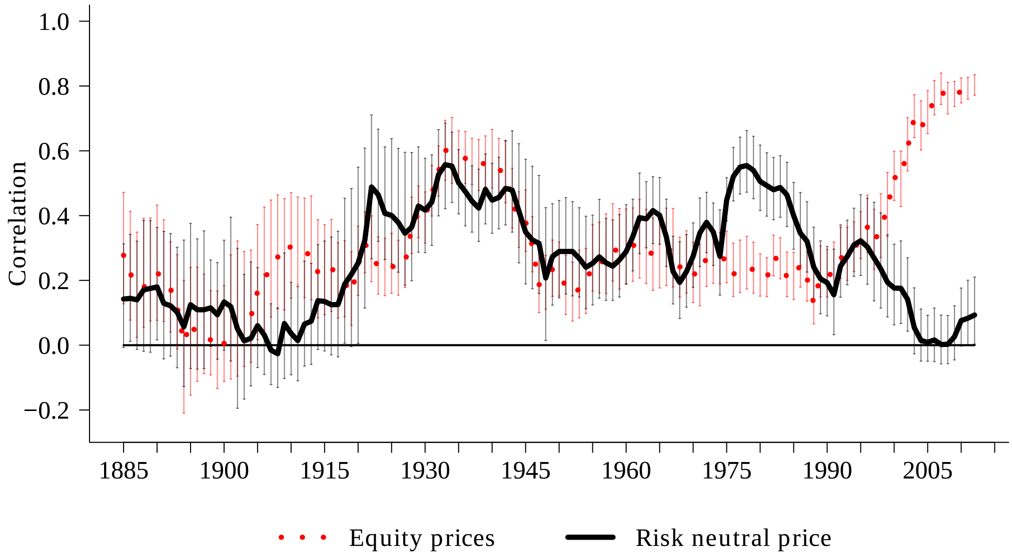
Using this basic asset pricing machinery, we can then ask: How much comovement in equity prices is due to comovement in the risk-neutral investor price? And how much is due to the remainder – "risk appetite"? For this we calculate Q^{RN} on the basis of future realized dividends and risk-free rates, assuming a terminal value at the sample end of $\frac{1}{1-\Delta\bar{D}/\bar{R}}$, where $\Delta\bar{D}$ indicates the sample median growth rate of CPI-deflated dividends, and $\bar{R}$ is the sample average of gross short-term safe rates. Given the terminal value we then calculate Q^{RN} recursively through $Q_{t-1}^{RN} = D_t/R_t + Q_t^{RN}/R_t$ (see Shiller, 1981*a*,*b*).[3]

Note that the asset pricing equation 3.1 is formulated in expectations. Here we follow Shiller (1981*a*,*b*) in equalizing ex ante expected values for dividends and risk-free rates with their ex post realized values. In the following, an important caveat to be aware of is that the ex post realized values cease to be good indicators of their ex ante expected counterparts whenever expectation errors become large. However, even if expectation errors play a role, seeing how much equity price comovement would have been justified by ex post realized fundamentals is nevertheless interesting. A more elaborate decomposition that attempts to model expectations through a vector autoregressive (VAR) system is presented in Appendix C (the decomposition is based on the methodology laid out in Campbell and Shiller, 1988; Campbell, 1991; Ammer and Mei, 1996). The results of this VAR decomposition are in line with the results of the simpler analysis discussed in the remainder of this section.

How much of total equity price comovement can be attributed to ex post realized dividends and risk-free rates? Figure 3.5 provides the answer. Until the late 20th century the comovement in actual equity prices is mostly accounted for by the comovement in the risk-neutral investor prices Q^{RN}, i.e. dividends and risk-free rates. Beginning in the late 20th century, however, equity price comovement starts to transcend its fundamentals. After 1990, Q^{RN} turns out to justify only a small amount of equity price comovement. In fact, as a result of the realized

[3]While the terminal value influences the level of Q^{RN} at the end of the sample, the comovement results, which are based on the detrended Q^{RN}, look very similar for a broad range of terminal value assumptions.

Figure 3.5: *Average bilateral equity price correlation*



Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands. *ST* refers to real short-term and *LT* to real long-term rates respectively.

covariance between dividends and risk-free rates, Q^{RN} turns out to justify a smaller amount of equity price comovement than what might have been guessed from the comovement in risk-free rates and dividends.

We are not the first to document that international equity price comovement in the late 20th century has become increasingly dominated by factors other than dividends and risk-free rates. Ammer and Mei (1996) and Engsted and Tanggaard (2004) report related findings for the U.S. and U.K. stock markets and Jordà et al. (2017*a*) report similar results for the economies in our sample. More recently, Miranda-Agrippino and Rey (2015) have shown that a substantial part of global asset returns since the 1990s can be explained by one global factor that is closely and inversely related to measures of market volatility and risk aversion. With this paper, we are the first to show that this is a novel development in the history of international financial integration that was not present in the first era of global finance.

3.4. Monetary policy and synchronization of risk taking

What might explain that risk appetite in global equity markets is increasingly synchronized? A popular view, often embraced by practitioners in financial markets, is that monetary policy in global financial centers, in particular the Federal Reserve, plays an important role in explaining risk-taking in international financial markets.

Such effects can occur through different channels as existing studies argue (Bekaert, Hoerova and Duca, 2013; Miranda-Agrippino and Rey, 2015). Fed policy may internationally synchronize the balance sheet capacity of financial intermediaries through its effect on asset prices (Ward, 2018). U.S. monetary policy may also directly act as a focal point that synchronizes risk perceptions of international investors (see Bacchetta and van Wincoop, 2013). The U.S. dollar is also an important vehicle currency that underpins today's global financial system (Shin, 2012). U.S. monetary policy decisions may thus have global reach (Kim, 2001; Canova, 2005). Ehrmann, Fratzscher and Rigobon (2011) show that about 30% of the fluctuations in euro area financial markets can be attributed to U.S. financial market fluctuations. Theoretically, Bruno and Shin (2013) propose a model in which global banks, with access to the financial center's wholesale money markets, transmit the financial center's financing conditions to regional banks around the world. Cetorelli and Goldberg (2012) present related econometric evidence on how global banks contribute to the international transmission of liquidity shocks through the lending conducted by their foreign affiliates.

3.4.1. Methods

To investigate whether monetary policy in financial centers is a driver of risk appetite, we estimate a set of cumulative impulse response functions using local projections (Jorda, 2005).[4] We begin with the following specification:

$$\Delta_h y_{i,t+h} = \alpha_i^h + \sum_{k=1}^{5} \beta_k^h \Delta y_{i,t-k} + \sum_{k=0}^{5} \gamma_k^h \Delta R_{t-k}^c + \sum_{k=0}^{5} \delta_k^h X_{i,t-k} + u_{i,t+h}, \quad h = 1, \ldots, H \tag{3.6}$$

where α_i are country-fixed effects, $\Delta_h y_{i,t+h} = y_{i,t+h} - y_{i,t-1}$ is, by our convention, the h-year cumulative growth rate of y, ΔR^c is the first difference in the center country's short-term rate, X_i is vector of control variables and $u_{i,t+h}$ are error terms. The parameters $\{\gamma_0^h\}_{h=1,\ldots,H}$ in expression (3.6) allow us to sketch out the behavior of equity prices, dividends and risk-free rates over the H years following a center country interest rate change ΔR_t^c. Note that this specification allows for a contemporaneous effect of the controls and center rate changes on the outcome variable.

Our impulse variable is the change in policy in the financial center, R^c. Later, we will corroborate the results with monetary policy "shock" measures, thus capturing the unanticipated part of policy changes in recent decades. The idea is to account for potential cross-country endogeneity contamination.

The U.S. was not always the world's financial center country. In the 19th century the U.K.'s financial system and currency played a similarly central role. The measure R^c is therefore the U.K. short-term rate prior to 1914 and the U.S. short-term rate after 1947. During the interwar

[4]It is reasonable to expect a certain degree of cross-sectional dependence in an international macroeconomic dataset, because countries are likely to be influenced by common disturbances. Also typical of macroeconomic data, these disturbances are likely to exhibit temporal persistence. In order to account for such cross-sectional and temporal dependencies in our data we calculate confidence bands based on Driscoll-Kraay standard errors with five autocorrelation lags (Driscoll and Kraay, 1998). Driscoll-Kraay standard errors are a nonparametric technique that is robust to very general forms of dependencies across time and space. The technique is well suited to our macroeconomic dataset, because it relies on large T asymptotics, without placing any restrictions on the limiting behavior of the number of countries.

years, the U.S. became the world's most important financial center according to some metrics, while the U.K. retained this title until WW2 according to others (see Chiţu, Eichengreen and Mehl, 2014*b*). Hence, we construct R^c as the average of U.S. and U.K. short-term rates for the interwar years.

The control variables are five lags of the log differences of GDP, CPI, equity prices, house prices, total loans, as well as housing return premiums, equity return premiums and short-term rates. We additionally control for five lags of the center country's growth rates in per capita GDP and inflation. Finally, we also include the center country's equity prices into the vector of controls as Rigobon and Sack (2004) document that the Fed is more likely to raise rates when the stock market has gone up and vice versa (also see Chadha, Sarno and Valente, 2004; Bjørnland and Leitemo, 2009; Castelnuovo and Nisticò, 2010; Furlanetto, 2011).

Moreover, in order to test whether financial center monetary policy explains the increase in the comovement of equity return premiums and risk appetite we separate the equity price impulse responses into two parts. Log-linearizing equation (3.1) around a balanced growth path yields an expression that can be used to calculate that part of the equity price response which is justified by the dividend and real rate responses, Q^{RN} (see Galí and Gambetti, 2015):

$$q_t^{RN} = \sum_{k=1}^{\infty} \left(\frac{\overline{D}}{\overline{R}}\right)^k \left[\left(1 - \frac{\overline{D}}{\overline{R}}\right) E_t\{d_{t+k-1}\} - E_t\{r_{t+k}\}\right] + k, \tag{3.7}$$

where small letters denote the logarithms of the original variables, $\overline{D}$ is the gross dividend growth rate along the balanced growth path, $\overline{R}$ is the respective interest rate, $\overline{D}/\overline{R} := C < 1$ and k denotes a linearization constant (see Cochrane, 2009, p.395). In the following we set C to 0.96. On the basis of expression (3.7) we can calculate the equity price (cumulative) response that is implied by any given dividend and interest rate response as:

$$\sum_{k=0}^{\infty} \frac{\partial q_{t+k}^{RN}}{\partial R_t^c} \Delta R_t^c = \sum_{j=1}^{\infty} C^k \left[(1-C)\sum_{k=0}^{\infty} \frac{\partial d_{t+k+j-1}}{\partial R_t^c} \Delta R_t^c - \sum_{k=0}^{\infty} \frac{\partial r_{t+k+j}}{\partial R_t^c} \Delta R_t^c\right]. \tag{3.8}$$

The difference between the cumulative response in actual equity prices Q and the cumulative response implied by dividends and risk-free rates Q^{RN} reflects the excess response of equity prices due to time-varying risk appetite ρ. For the practical calculation of the cumulative risk-neutral price response the infinite sums for the dividend and risk-free rate responses have to be replaced by a finite sum. We opted for seven-year cumulative responses because the dividend and risk-free rate responses are statistically indistinguishable from zero at higher time horizons.

Note that, as in section 3.3, we equalize ex ante expected dividends and risk-free rates with their ex post realized counterparts. We challenge this assumption in a robustness check in appendix 3.A.3, where we evaluate the international effect of financial center monetary policy within a VAR decomposition framework along the lines suggested by Bernanke and Kuttner (2005).

3.4.2. *The response of global equity markets*

Figure 3.6 shows the response of equity prices (Q) and risk-neutral equity prices (Q^{RN}), as well as the dividend- (D) and interest rate (R) responses from which the Q^{RN}-response was derived from. The risk-neutral response is the response that shows how a risk-neutral investor would value equity on the basis of future dividends that are discounted with the risk-free rate. The risk-neutral price response is labelled 'Risk-neutral' in the figure. The left column in Figure 3.6 shows the full sample results, while the right column focuses on the post 1980 subsample in order to focus on the period of rising comovement in global risk appetite.

Our first key result is that the response of equity prices has become stronger over time. The international response to a +1 ppt center interest rate hike has almost doubled from the full sample average of about -4% to the post-1980 trough of -8%. Furthermore, the negative response has grown more persistent.

Partly this is due to international dividends and real short-term rates having become more sensitive to changes in U.S. monetary policy. In the full sample dividends fell on average by about 2.5% and interest rates peaked at 0.5 ppt. Since 1980 the respective numbers have gone up to 5% and 0.75 ppt respectively. Stronger global dividend and real rate reactions to U.S. monetary policy, however, are insufficient to explain the stronger equity price responses.

The implied risk-neutral equity price Q^{RN}, calculated according to equation (3.8) from the dividend and interest rate responses alone, suggests that dividend and safe rate responses explain only about 25% of the post-1980 equity price response over 4 years. Fluctuations in risk appetite are by far the most important driver, accounting for three quarters of the response.

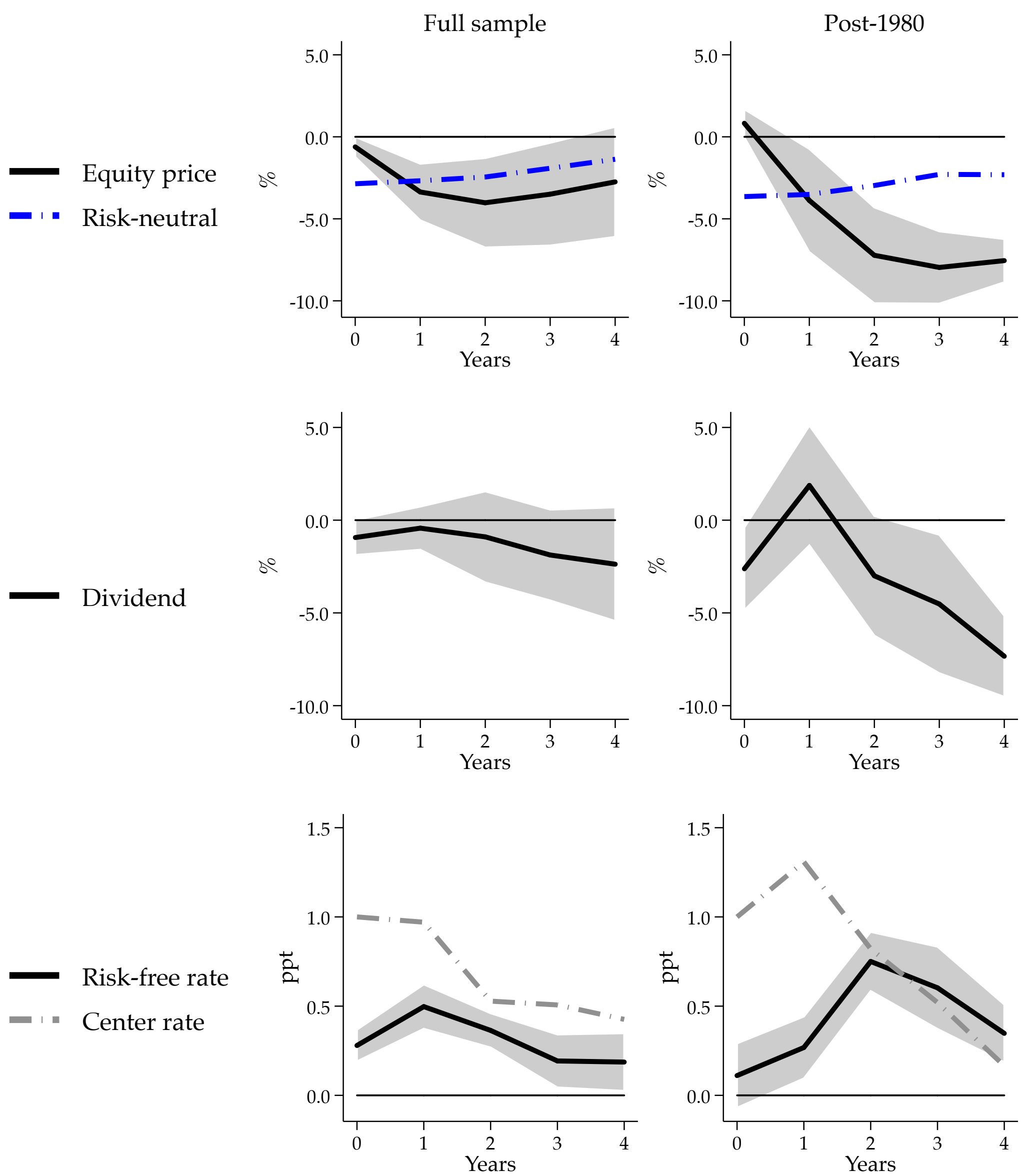
Moreover, Figure 3.7 shows how much stronger the response has become from one globalization era to the next. Before 1914, equity markets reacted to rate changes much as would be expected from a risk-neutral investor. Equity prices declined in response to a 100 bp increase of the policy rate of the Bank of England, but there is no major impact above and beyond the risk neutral path. In the post-1980 globalization, this effect is magnified by the effect on risk appetite.

3.4.3. *Expected equity return premium responses*

So far we have looked at the reaction of global risk appetite to center-country policy shocks only indirectly, by separating the fundamental component Q^{RN} from the actually realized equity price response Q. The resulting difference between the two responses indicates changes in risk appetite. Alternatively, we can look at the direct response of the equity return premium, ERP. The difficulty here is that we are interested in the ex-ante expected equity return premium as a measure of global risk appetite. However, we only observe the ex-post realized equity return premium.

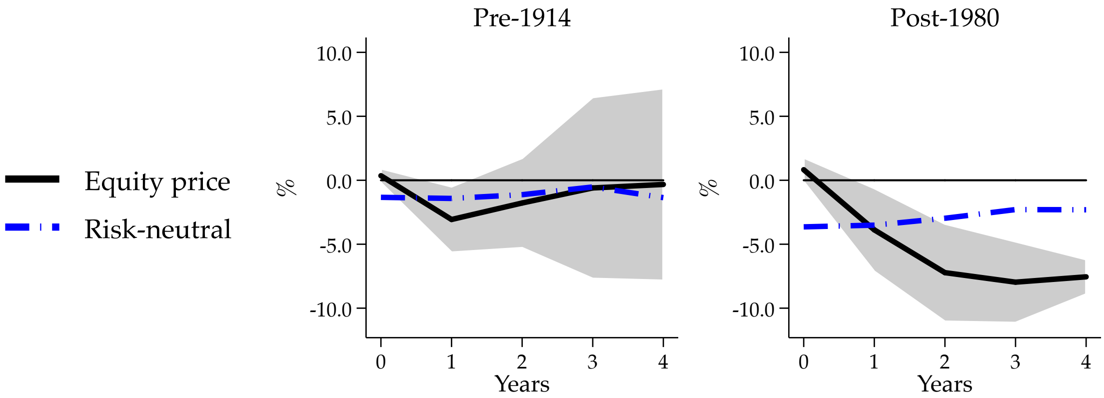
In order to get a sense of the response of the *ex-ante* expected equity return premium to center-country monetary policy changes we propose a strategy that allows us to derive a lower bound estimate of the response of *ex-ante* expected equity return premiums from their *ex-post* realized counterparts. Specifically, the expected equity return premium $E_t(ERP_{t+1})$ can be

Figure 3.6: *Decomposing the global equity market response*



Notes: Cumulative impulse response functions to +1ppt increase in financial center interest rates. Risk-neutral – risk neutral price (Q^{RN}). Center rate – financial center (U.K. and/or U.S.) short-term risk-free rate own response. Confidence bands calculated on the basis of Driscoll-Kray standard errors. Risk neutral price (Q^{RN}) calculated according to equation (3.8).

Figure 3.7: *Pre-1914 vs. Post-1980 equity price responses*



Notes: Cumulative impulse response functions to +1ppt increase in financial center interest rates. Risk-neutral – risk neutral price (Q^{RN}). Center rate – financial center (U.K. and/or U.S.) short-term risk-free rate own response. Confidence bands calculated on the basis of Driscoll-Kray standard errors. Risk neutral price (Q^{RN}) calculated according to equation (3.8).

decomposed into the ex-post realized equity return premium ERP_{t+1} and an expectation error η_t:

$$\underbrace{E_t(ERP_{t+1})}_{\text{ex-ante expected ERP}} = \underbrace{ERP_{t+1}}_{\text{ex-post realized ERP}} - \eta_t. \tag{3.9}$$

Recall the *ex-post* realized equity return premium $ERP_{t+1} = \frac{Q_{t+1}+D_{t+1}}{Q_t} - R_{t+1}$. In order to determine how the ex-ante expected equity return premium reacts to center-country monetary policy changes, we need to know how the expectation error η reacts.

Under rational expectations, the expectation error η_t is fully explained by exogenous innovations to the shock process and is restricted to the period in which the shock occurs—the contemporaneous period. Thus, we only need an estimate for the expectation error in the contemporaneous period, η_0, in order to translate the ex post realized ERP response into the ex ante expected ERP response.

An estimate for η_0 can be obtained by assuming that the contemporary response of the ex-ante expected ERP is 0—a conservative estimate as will be discussed in a moment:

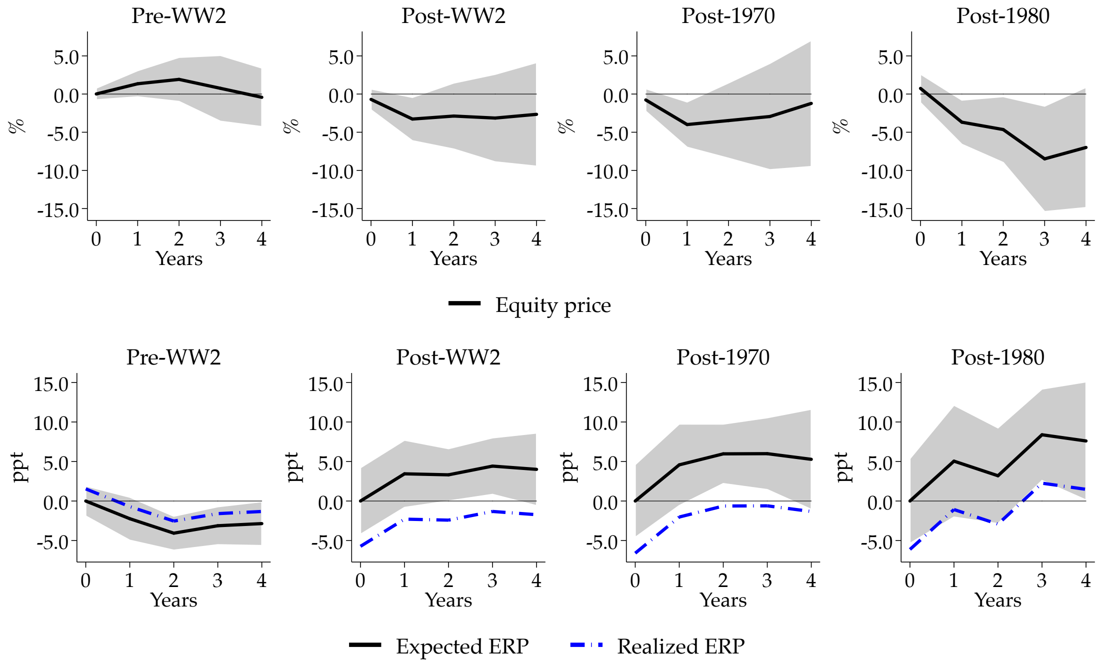
$$\frac{\partial E_0(ERP_1)}{\partial R_0^c}\Delta R_0^c = 0 \tag{3.10}$$

This implies that, the estimated contemporaneous response of the ex post realized ERP constitutes an estimate of the contemporaneous expectation error η_0:[5]

$$\eta_0 = \frac{\partial ERP_1}{\partial R_0^c}\Delta R_0^c - \frac{\partial E_0(ERP_1)}{\partial R_0^c}\Delta R_0^c = \frac{\partial ERP_1}{\partial R_0^c}\Delta R_0^c \tag{3.11}$$

[5]This is assuming that innovations to center-country rates are not correlated with other shocks. For correlated shocks the contemporaneous response reflects expectation errors related to different shocks.

Figure 3.8: *Equity prices and equity return premiums*



Notes: Cumulative impulse response functions to +1ppt increase in financial center interest rates. Confidence bands calculated on the basis of Driscoll-Kray standard errors.

On the basis of this estimate for η_0, the cumulative response of the ex ante expected ERP can simply be calculated as the cumulative response of the ex post realized ERP shifted by the expectation error η_0:

$$\underbrace{\sum_{h=0}^{\infty} \frac{\partial E_{t+k}(ERP_{t+1+h})}{\partial R_t^c} \Delta R_t^c}_{\text{expected ERP response}} = \underbrace{\sum_{h=0}^{\infty} \frac{\partial ERP_{t+1+h}}{\partial R_t^c} \Delta R_t^c - \eta_0}_{\text{realized ERP response}} \tag{3.12}$$

Note that the resulting impulse response function estimate constitutes a lower bound estimate, in the sense that most empirical studies on the effects of monetary policy on risk premiums and risk taking suggest that within the first 12 months after a contractionary monetary policy shock risk premiums are up and risk appetite is down (see Bernanke and Kuttner, 2005; Bekaert, Hoerova and Duca, 2013; Bruno and Shin, 2015; Gertler and Karadi, 2015). Thus, assuming a 0 contemporary response in the ex-ante expected ERP (see equation 3.10) is conservative.

Figure 3.8 depicts the resulting impulse response function estimates for the ex ante exptected ERPs (solid black line), ex post realized ERPs (dashed blue line), as well as equity prices for various subsamples. The figure shows that the global impact of financial center-country monetary policy on global equity prices is mostly a post-WW2, and in particular a post-1980 phenomenon. Within the post-WW2 sample, the global response of the ERP grows stronger over time, with equity prices decreasing by about 10% from trend value after a 1ppt FED rate hike. The expected ERP that investors require to hold equity increases by 5 to 10 ppts. In light of these results, U.S. monetary policy is indeed a powerful driver of return premiums in global equity markets.

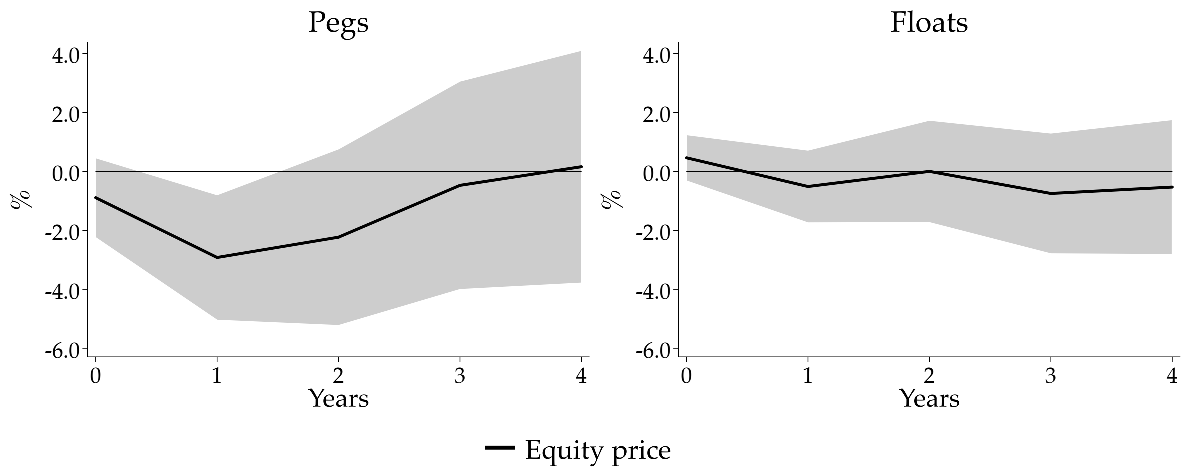
Table 3.1: *Exchange rate regime and equity price responses, full sample*

(a) *Impulse response functions: Table and test for equality*

	(1) Year 0	(2) Year 1	(3) Year 2	(4) Year 3	(5) Year 4
Pegs	-0.88	-2.91***	-2.22	-0.46	0.16
	(0.69)	(1.08)	(1.52)	(1.80)	(2.01)
Floats	0.46	-0.50	0.00	-0.74	-0.52
	(0.40)	(0.62)	(0.88)	(1.04)	(1.16)
Peg=Float (p-value)	0.05*	0.02**	0.14	0.87	0.73
Observations	810	810	810	810	810
R^2	0.57	0.57	0.44	0.37	0.31

Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Wald test for equality of peg and float responses.

(b) *Impulse response functions: Figures*



3.4.4. Exchange rate regimes

Risk-appetite spillovers of US monetary policy are substantial. Do floating exchange rates help countries avoid such spillovers? Floating exchange rates are thought to insulate domestic interest rates from foreign interest rates. But it is unclear whether this insulation generalizes to risk premiums and risk appetite more generally. It is natural to ask the extent to which floating exchange rates effectively decouple domestic financial conditions from substantial comovements in risk appetite. To address this question we condition our previous analysis on a country's exchange rate regime.

The classification of the exchange rate regime has occupied international economists for a long time (Klein and Shambaugh, 2015). Before WW2 our peg dummy follows Obstfeld, Shambaugh and Taylor (2004) and Obstfeld, Shambaugh and Taylor (2005); thereafter we rely on the exchange rate regime classification scheme of Ilzetzki, Reinhart and Rogoff (2008) for 1940-1959, and the Shambaugh exchange rate classification dataset for 1960-2014 (Shambaugh, 2004; Klein and Shambaugh, 2008; Obstfeld, Shambaugh and Taylor, 2010).

Table 3.2: *Exchange rate regime and equity price responses, post-1945*

(a) *Impulse response functions: Table and test for equality*

	(1) Year 0	(2) Year 1	(3) Year 2	(4) Year 3	(5) Year 4
Pegs	-1.46	-8.36**	-6.94	3.05	6.63
	(2.23)	(3.79)	(5.55)	(6.46)	(7.17)
Floats	0.94*	-3.10***	-1.17	0.12	-0.06
	(0.57)	(0.97)	(1.43)	(1.66)	(1.85)
Peg=Float (p-value)	0.27	0.15	0.29	0.64	0.34
Observations	577	577	577	577	577
R^2	0.74	0.70	0.55	0.52	0.48

Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Wald test for equality of peg and float responses.

(b) *Impulse response functions: Figures*

Our peg dummy takes the value of 1 if a country was on the gold standard before 1940. From 1940 onwards, it takes the value of 1 for economies whose exchange rate stays within a +/- 2% band, and 0 otherwise. We follow Obstfeld, Shambaugh and Taylor (2005) in not considering one-off realignements as breaks in the peg regime. Similarly, single-year pegs are recoded as floats, as they quite likely simply reflect a lack of variation in the exchange rate.

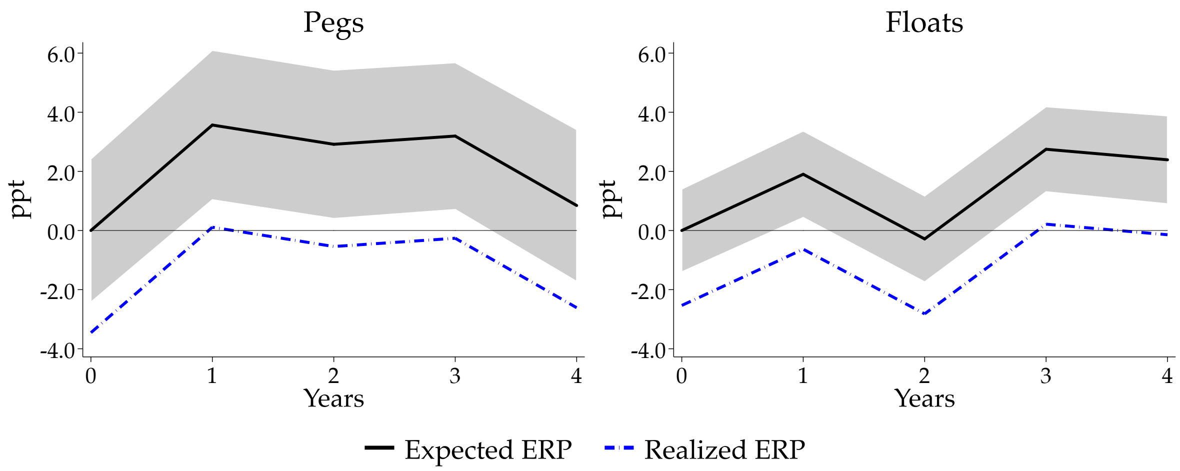
Table 3.3: *Exchange rate regime and equity return premium responses, full sample*

(a) *Impulse response functions: Table and test for equality*

	(1) Year 0	(2) Year 1	(3) Year 2	(4) Year 3	(5) Year 4
Pegs	0.00	3.56***	2.91**	3.19**	0.84
	(1.23)	(1.28)	(1.28)	(1.26)	(1.31)
Floats	0.00	1.90**	-0.28	2.74***	2.39***
	(0.71)	(0.74)	(0.74)	(0.73)	(0.75)
Peg=Float (p-value)	1.00	0.56	0.07*	0.71	0.06
Observations	810	810	810	810	810
R^2	0.43	0.46	0.45	0.48	0.43

Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Wald test for equality of peg and float responses (based on realized ERP).

(b) *Impulse response functions: Figures*



Using this exchange rate indicator, we estimate local projections according to the following specification:

$$
\begin{aligned}
\Delta_h y_{i,t+h} = \alpha_i^h + \sum_{k=1}^{L} \beta_k^h \Delta y_{i,t-k} + \sum_{k=0}^{L} \gamma_k^h \Delta R_{t-k}^c \\
+ \sum_{k=0}^{L} \delta^h \Delta R_{t-k}^c \times float_{i,t} + \sum_{k=0}^{L} \eta_k^h X_{i,t-k} + u_{i,t-1+h}, \quad h = 1, \ldots, H
\end{aligned} \tag{3.13}
$$

where α_i are country-fixed effects, $\Delta_h y_{i,t+h}$ are h-year changes the dependent variable and $u_{i,t+h}$ are error terms.

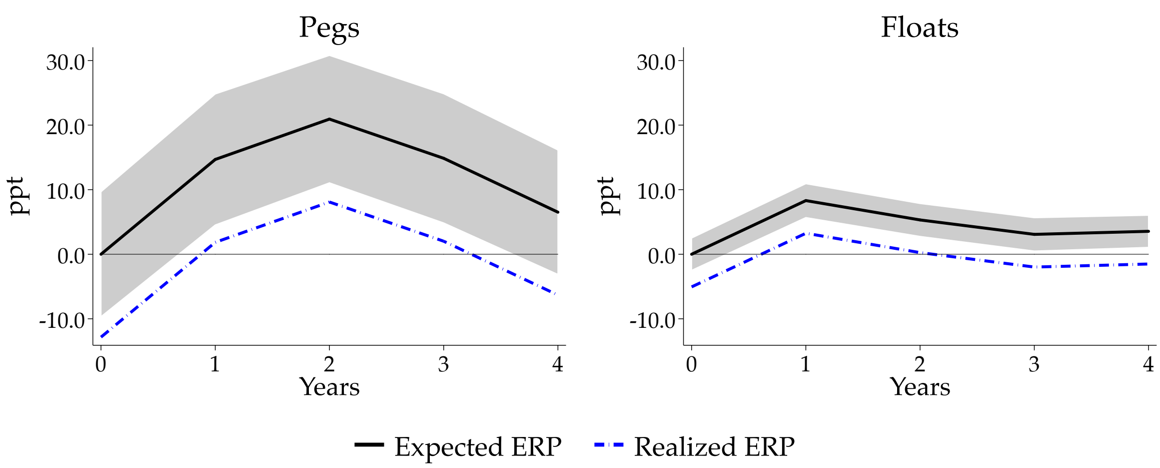
Table 3.4: *Exchange rate regime and equity return premium responses, post-1945*

(a) *Impulse response functions: Table and test for equality*

	(1) Year 0	(2) Year 1	(3) Year 2	(4) Year 3	(5) Year 4
Pegs	0.00	12.73**	19.38***	12.85**	4.84
	(4.96)	(5.03)	(5.06)	(4.93)	(4.87)
Floats	0.00	7.64***	4.83***	3.36***	3.29***
	(1.28)	(1.30)	(1.30)	(1.27)	(1.25)
Peg=Float (p-value)	1.00	0.72	0.12	0.58	0.26
Observations	577	577	577	577	577
R^2	0.52	0.56	0.54	0.59	0.59

Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Wald test for equality of peg and float responses (based on realized ERP).

(b) *Impulse response functions: Figures*



The $\{\gamma_0^h\}_{h=1,\ldots,H}$ in expression (3.13) allows us to sketch out the average behavior of international risky and safe interest rates over the H years following a center-country policy rate shock ΔR^c. The $\{\delta_0^h\}_{h=1,...,H}$ allow us to investigate the difference in the response between pegs and floaters. $float_{i,t}$ is a dummy variable that is 1 in periods when the exchange rate with respect to the center-country floats, has been floating for the previous 3 years, and will be floating for the following 4 years (i.e. the entire projection horizon). Analogously the dummy is 0 in years when the exchange rate is fixed in the current year, was fixed throughout the previous 3 years and continuous to be fixed in the 4 years to come. This definition ensures that estimated impulse response functions clearly distinguish between pegs and floats. In all cases we make use of the bilateral peg dummy describing the exchange rate regime status between any country and the center-country. In addition to the control variables used previously (see equation (3.6)) X now also includes a binary indicator for the existence of capital controls. The capital control dummy is described in detail in Jordà, Schularick and Taylor (2015).

Figures 3.1b and 3.3b show the international responses of equity prices and ERP for the full sample. The equity price- and ERP responses tend to be stronger for countries whose exchange rate is pegged to the USD. Over the full sample, equity prices are down by 3% in year 1, while there is no significant response among floats. On average pegs' risk appetite still tends to be more affected than floaters' risk appetite although the effects are weak. Tables 3.1a and 3.3a show the impulse responses for pegs and floats and the p-value for a Wald-test for equality of the impulse responses. The tests confirm that historically the response to center-country monetary policy changes has been significantly more pronounced for pegs.

We now turn to the post-WW2 subsample, as our previous results show that this is the period when risk premium spillovers were strongest. Figures 3.2b and 3.4b show the differential equity price- and ERP responses of pegs and floats to a +1ppt change in the U.S. rate. We find that for the post-WW2 sample the peg-float dichotomy is somewhat less clear. Floaters' equity prices and ERP now also show a pronounced response to center-country interest rate changes. Pegs on average still exhibit a stronger response. However, tables 3.2a and 3.2a show that Wald-test for equality of responses can no longer reject the null of equality at conventional confidence levels.

3.5. Monetary policy shocks

Although arguably exogenous from the perspective of a small economy, policy changes in the financial center might not be unanticipated. In order to address such anticipation concerns, this section corroborates the previously reported results using the instruments for monetary policy changes used by Gürkaynak, Sack and Swanson (2005) and Gertler and Karadi (2015) in a local projection instrumental variable (LPIV) framework (see Òscar Jordà, Moritz Schularick and Alan M Taylor, 2017). These instruments capture changes in futures markets in a short time window around FOMC rate decisions and thereby measures the "surprise" component of rate changes.

The local projection instrumental variable approach to estimating impulse responses using high frequency monetary policy instruments can be laid out as follows:

$$\Delta_h y_{i,t+h} = \alpha_i^h + \sum_{k=1}^{5} \beta_k^h \Delta y_{i,t-k} + \sum_{k=0}^{5} \gamma_k^h \Delta \hat{R}_{i,t-k}^c + \sum_{k=0}^{5} \delta_k^h X_{i,t-k} + u_{i,t+h}, \quad h = 1, \ldots, H, \tag{3.14}$$

where $\hat{R}_t^c$ is the prediction from a first stage regression of the effective federal funds rate R^c on the high frequency instruments used by Gürkaynak, Sack and Swanson (2005) and Gertler and Karadi (2015):

$$R_t^c = \zeta + \theta FF1_t + \omega FF3_t + \tau ED6_t + \nu ED9 + \chi ED12 + \epsilon_t, \tag{3.15}$$

where $FF1$, $FF3$, $ED6$, $ED9$ and $ED12$ are the high frequency instruments (HFI). In the order specified, they are the unexpected changes in the Federal Funds futures of the current month, the 3-month ahead monthly Fed Funds futures and the 6-, 9- and 12-month ahead futures on 3-month Eurodollar deposits. We aggregate the monthly first stage predictions up to the annual level by taking the total sum of the predicted values over the twelve months within each year. Due to the shorter time span for which the HFIs are available this setup only allows us to compare the post-1990 impulse response functions.

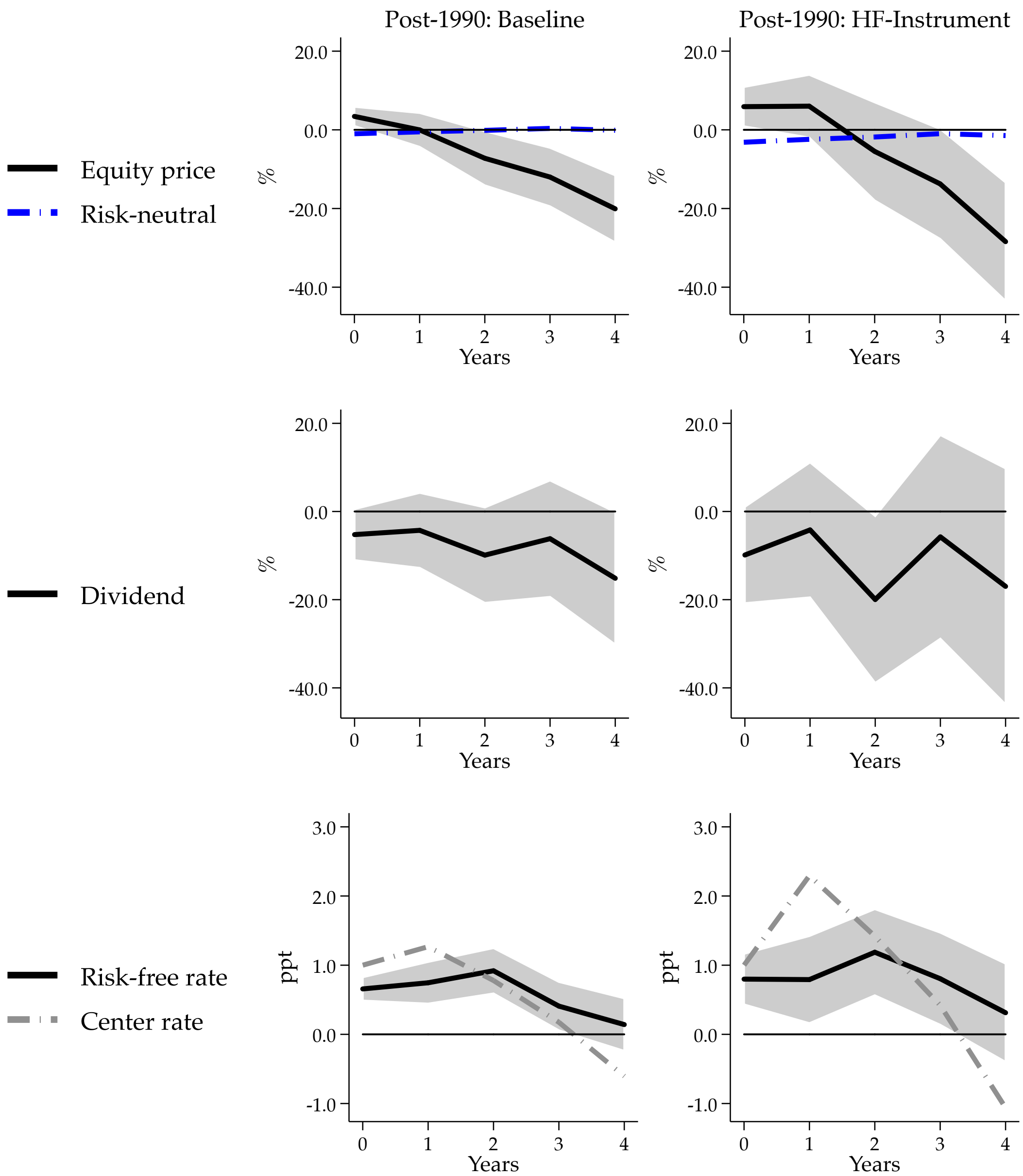
The first stage results are displayed in table 3.5. The HFIs are clearly relevant with R^2's ranging from 0.17 to 0.38, depending on which instruments are included. The following results are based on the specification including all HFIs (depicted in column 5).

The impulse responses we obtain for our baseline approach and the HFI approach are reassuringly similar in direction and magnitude, indicating that center-country interest rate changes can indeed be treated as largely exogenous for the rest of the world. Also note that the post-1990 responses are stronger than the post-1980 ones, indicating that the impact of U.S. monetary policy on the rest of the world has grown over time—similar to the results we presented above.

3.6. Discussion

What explains the late 20th century rise in international risk premium synchronization? The post-Bretton Woods synchronization of risk-premiums coincides with a rollback of capital controls and financial liberalization. These changes may lead to an increase in the international synchronization of risk premiums via the balance sheets of financial intermediaries (Ueda, 2012). Cross-country market integration of safe and risky assets should, by arbitrage, lead to an international equalization of the return on assets within the same risk-class, and hence an international equalization of risk premiums (Dedola and Lombardo, 2012). Kollmann, Enders and Müller (2011) and Alpanda and Aysun (2014) present theoretical accounts where the equalization of global returns springs from the optimization problem of a global bank that aims to equalize its returns across regions. The observation that the post-Bretton Woods synchronization of risk premiums coincides with a period of capital account liberalization is consistent with such models. However, explanations based on financial openness beg the

Figure 3.9: *Decomposing the global equity price response (high frequency instruments)*



Notes: Cumulative impulse response functions to +1ppt increase in financial center interest rates. Risk-neutral – risk neutral price (Q^{RN}). Center rate – U.S. short-term risk-free rate own response. Confidence bands calculated on the basis of Driscoll-Kray standard errors. Risk neutral price (Q^{RN}) calculated according to equation 3.8.

question of why extensive risk premium comovement did not occur already during the first era of financial globalization before 1914 (Quinn and Voth, 2008).[6]

[6]The extent of international financial market integration in the late 19th and late 20th centuries differs in several respects. While (net) cross-border capital flows and (net) foreign asset positions are comparable across both globalizations (Obstfeld and Taylor, 2004), financial globalization in the late

Table 3.5: *First stage regression results*

	(1)	(2)	(3)	(4)	(5)
FF1	1.88***		1.22***		1.46***
	(0.15)		(0.26)		(0.28)
FF3		2.13***	0.93***		1.08***
		(0.19)	(0.32)		(0.38)
ED6				1.41*	-1.75*
				(0.80)	(0.89)
ED9				1.92	0.90
				(1.38)	(1.26)
ED12				-1.84**	0.52
				(0.91)	(0.78)
R^2	0.35	0.31	0.36	0.17	0.38
Observations	284	270	270	342	270

Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Dependent variable: federal funds target rate change in ppts.
All variables in ppts changes; monthly observations.

Behavioral theories of financial market behavior also offer explanations for investor overreaction. Behavioral theories attribute excess variation in asset prices to systematic mis-judgements in human psychology (Kahneman and Tversky, 1979; Shiller, 2000; Akerlof and Shiller, 2010) and to collective manias and panics (Kindleberger, 1978). The wedge that such "animal spirits" drive between fundamentals and asset valuations can help understand observed asset pricing puzzles (Gennaioli and Shleifer, 2010; Bordalo, Gennaioli and Shleifer, 2012). If globally synchronized, behavioral forces could explain the excess international comovement of equity prices that we observe. For example, in a globalized world economy with global news flows, investors' sentiment can be synchronized by their exposure to a similar set of information.

Our empirical investigation does not provide conclusive evidence, but we note that the temporal pattern of international risk premium comovement again begs the question why behavioral forces did not induce excessive comovement in risk appetite in earlier periods of financial globalization when international investors presumably were subject to the same cognitive constraints and similar information flows.

A key difference between late 19th and late 20th century financial globalization concerns the international monetary system. Prior to 1914, global money aggregates were linked to global gold supply, which was fixed in the short run. As a consequence, global liquidity supply was inelastic in the short-run. On a regional level, this meant that gold inflows and credit

20th century encompassed a wider range of financial assets than did its late 19th century precursor (Bordo, Eichengreen and Kim, 1998). In particular late 19th century financial globalization was focused in industries with high tangible capital that were less plagued by information asymetries, such as railways, public bonds, mining and public utilities. Put differently, measured risk premiums might not be comparable across time.

expansions in one region tended to be offset by gold outflows and credit contractions in other regions, as David Hume famously analyzed (Hume, 1752). The pre-1914 gold standard thus introduced a desynchronizing force into global finance that may have impeded the emergence of globally synchronized risk premiums. In contrast, in the post-Bretton Woods period, global finance is built on a fiat money system that allows for a more elastic supply of liquidity. By and large, such a system is more likely to accommodate a globally synchronized expansion of liquidity supply and comovement in risk premiums. Such different elasticities of global liquidity in the pre-1914 and post-1970 financial globalizations could help to explain the temporal pattern of risk premium comovement we observe.

Another strain of the theoretical literature on global financial spillovers that could account for the observed temporal pattern of risk premium comovement relates to the form of international financial intermediation. What is new in the late 20th century financial globalization is that international banks play a central role (Cassis, Grossman and Schenk, 2016, ch.11). The earlier financial globalization was not dominated by leveraged financial intermediaries. Instead, wealthy private individuals and mutual funds were the main vehicles for international capital flows (see Michie, 1986; Feis, 1964).

If banks hold foreign assets on their balance sheets and mark them to market, price changes can synchronize the risk appetite and the trading behavior of banks around the world (Adrian and Shin, 2009; Miranda-Agrippino and Rey, 2015; Bruno and Shin, 2015; Ward, 2018). For instance, if Federal Reserve policy affects U.S. equity prices, falling asset prices in the U.S. decrease (risk-weighted)-asset-capital ratios of U.S. as well as *international* banks which start to cut down their risk-taking in sync with U.S. banks. If no large risk-neutral player steps in to compensate for the lower risk taking of the leverage-constrained intermediaries, risk-spreads will increase.[7]

Schularick and Taylor (2012) show that late 20th century banking is characterized by an explosion in bank credit and total bank assets, giving rise to a ”financial hockey stick” pattern in the global credit-to-GDP ratio, that is reminiscient of the temporal pattern in international risk premium correlations. That this ‘‘financial hockey stick” pattern is closely related to important international business cycle moments has already been established by Jordà, Schularick and Taylor (2016). For instance, investment and credit growth comovement increases in the bank credit-to-GDP ratio. The broad picture here is consistent with an important role of intermediary balance sheets for the amplification of international financial spillovers (Devereux and Yetman, 2010; Kollmann, Enders and Müller, 2011; Dedola and Lombardo, 2012; Alpanda and Aysun, 2014).

3.7. Conclusions

This paper documents the international synchronization of risk taking in recent decades. Our findings have important implications for economic policymaking around the world. The

[7]For open economy models where international spillovers become stronger in the level of intermediary leverage see Devereux and Yetman (2010) and Ueda (2012).

emergence of a U.S. led global financial cycle indicates that for policymakers in other countries, the world economy has become a considerably more demanding environment to operate in. Risk appetite spillovers, largely decoupled from domestic inflation, output or unemployment drive a wedge between conventional targets of monetary policy and financial stability targets. The divergence of real and financial policy targets may worsen the trade-offs involved in the application of existing policy instruments.

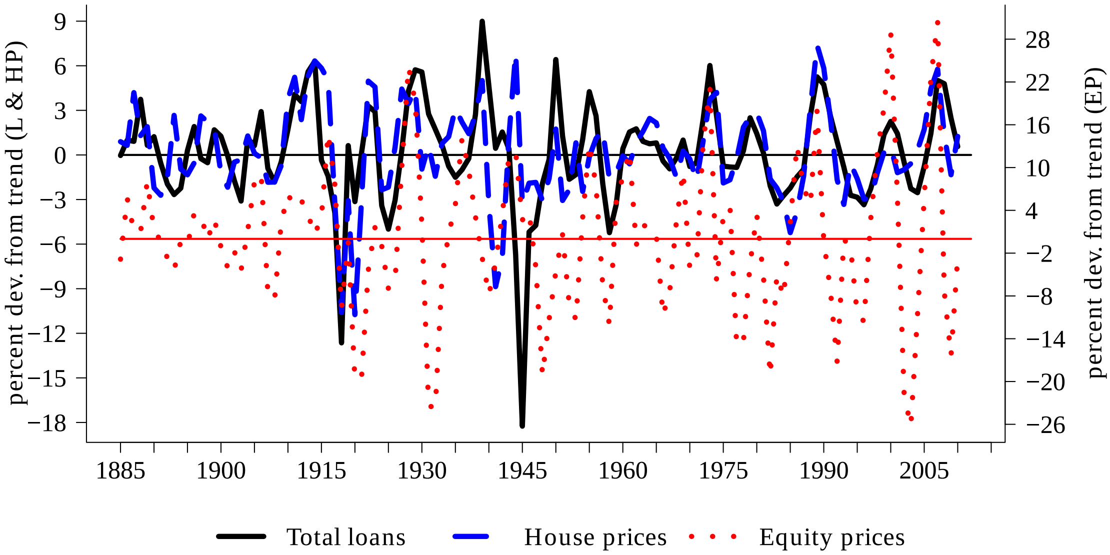
On a global level, the synchronization of financial conditions also raises the question about the scope for international economic policy coordination. The case for global policy cooperation rests on the existence of an inefficiency that cooperation could improve upon. The documented global synchronization of risk appetite, driven by U.S. monetary policy certainly warrants further investigations as to the possibilities of improving policy responses.

Small open economies that find themselves at the mercy of the ebb and flow of global risk appetite may consider broadening their range of policy tools in order to regain control of domestic policy targets. A broader range of national policy instruments enables national policymakers to counter inefficient spillovers even in the absence of international policy cooperation (see Korinek, 2016). What international or national economic institutions are best situated for monitoring and, if warranted, intervening into the international spillovers of risk appetite, is an important question.

3.A. Appendix

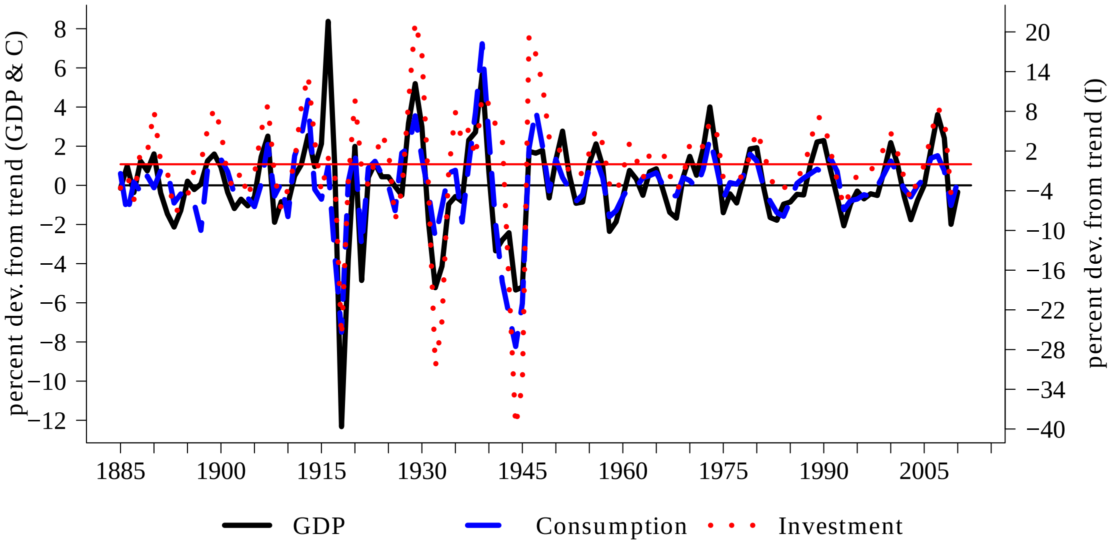
3.A.1. Global averages

Figure 3.10: *Financial cycles, global average (2-32 year cycles)*



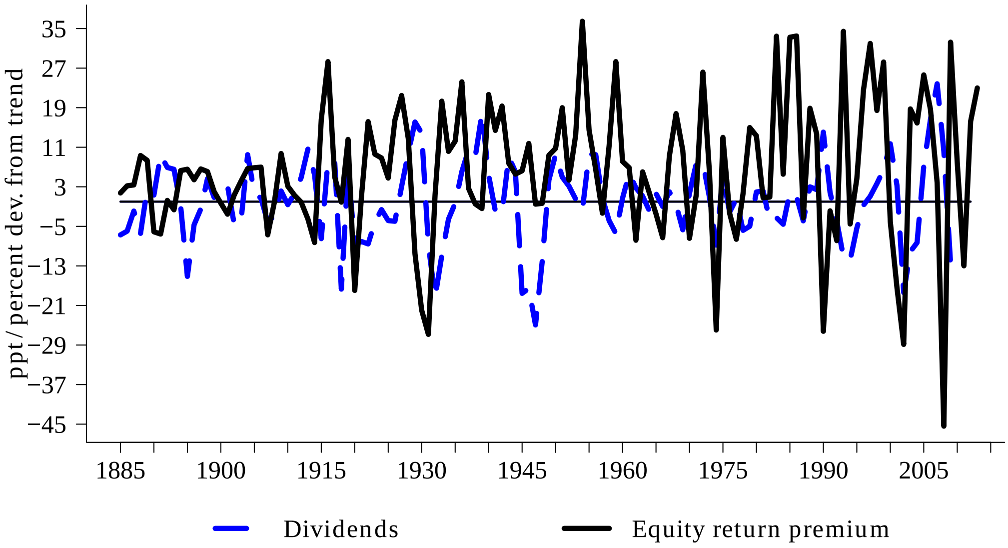
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 32-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.11: *Real cycles, global average (2-32 year cycles)*



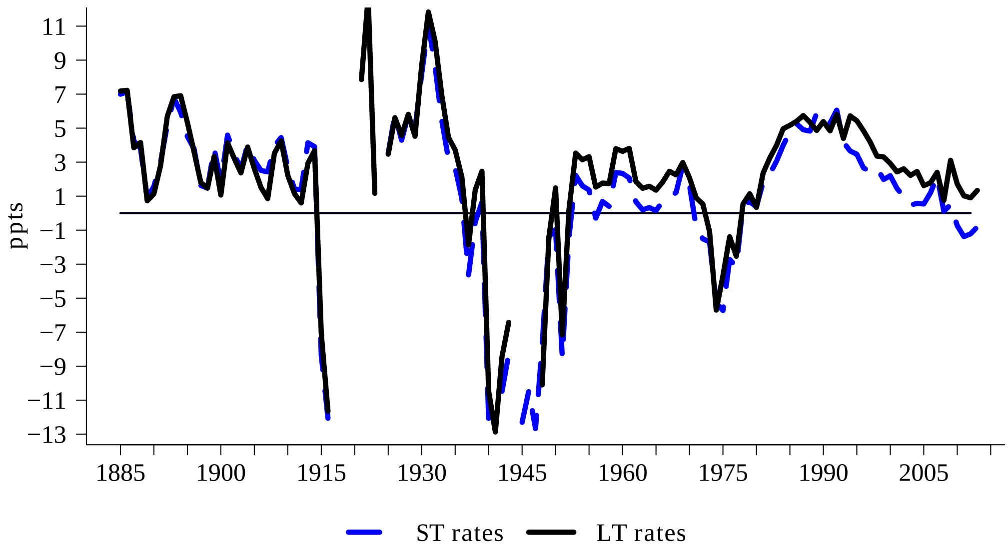
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 32-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.12: *Dividends (2-32 year cycles) and equity return premium, global average*



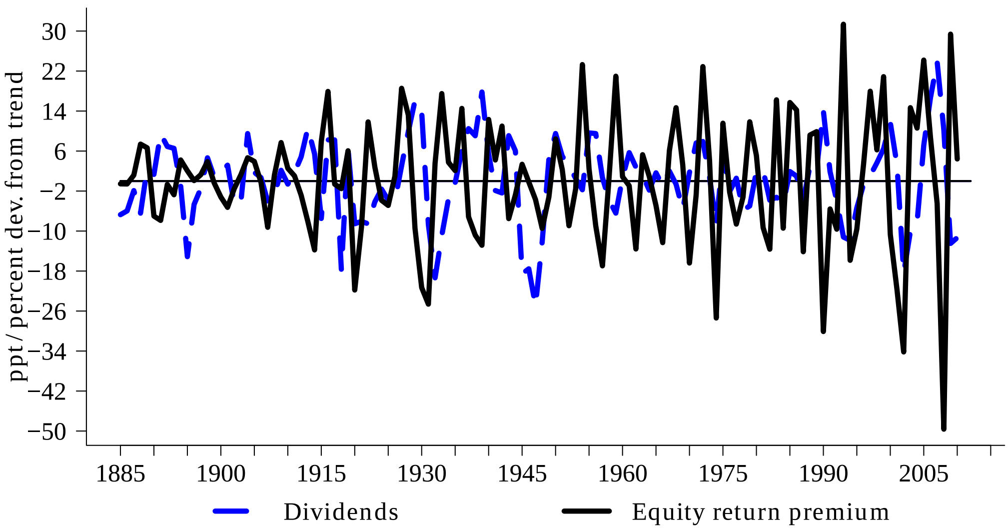
Notes: Global means. The dividend series was detrended with a Baxter-King filter isolating cycles in the 2 to 32-year period range. The equity return premium series is depicted in levels. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.13: *Interest rates, global average*



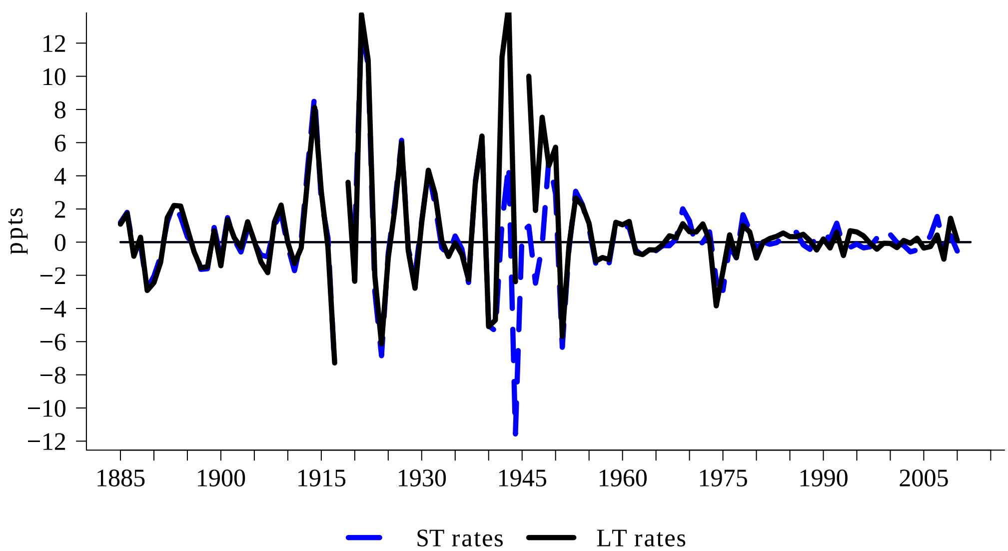
Notes: Global means. All series in levels. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.14: *Dividends and equity return premium, global average (2-32 year cycles)*



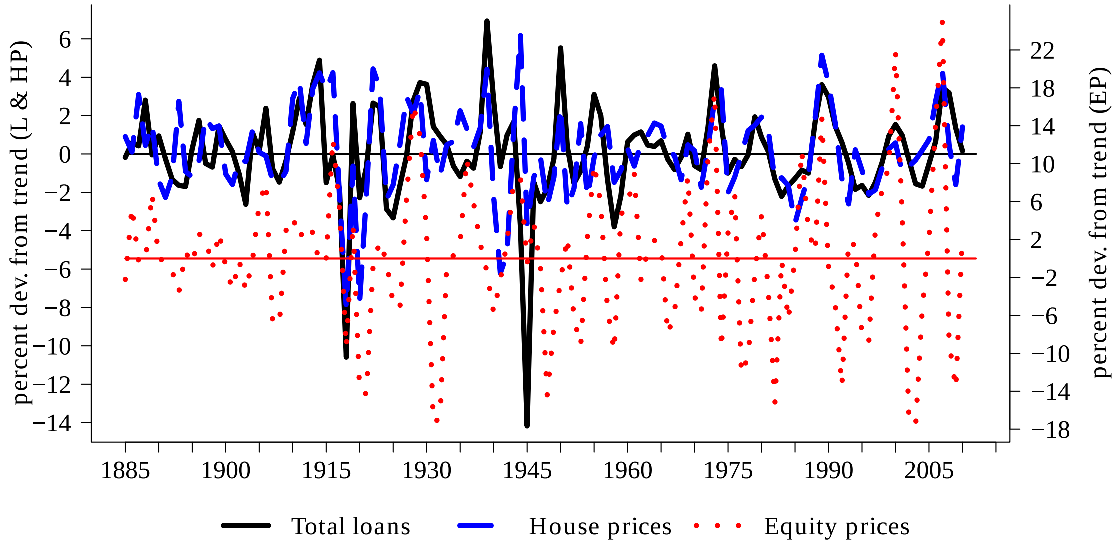
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 32-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.15: *Interest rates, global average (2-32 year cycles)*



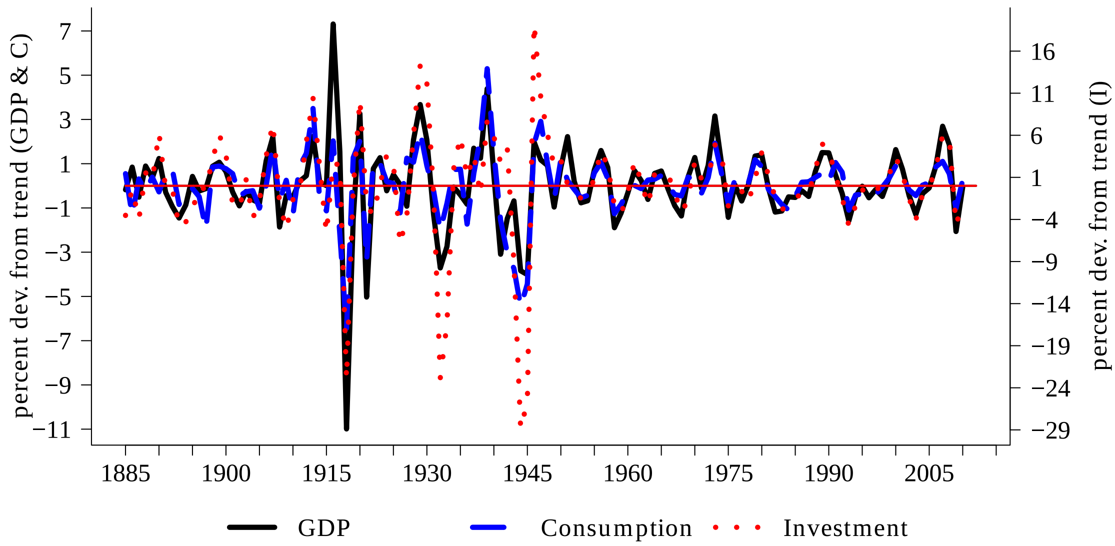
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 32-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.16: *Financial cycles, global average (2-8 year cycles)*



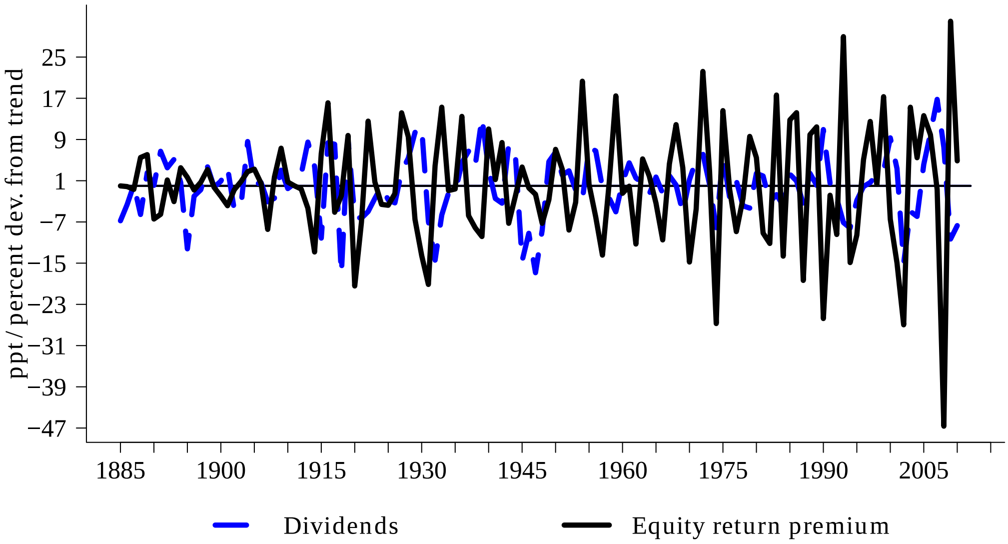
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 8-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.17: *Real cycles, global average (2-8 year cycles)*



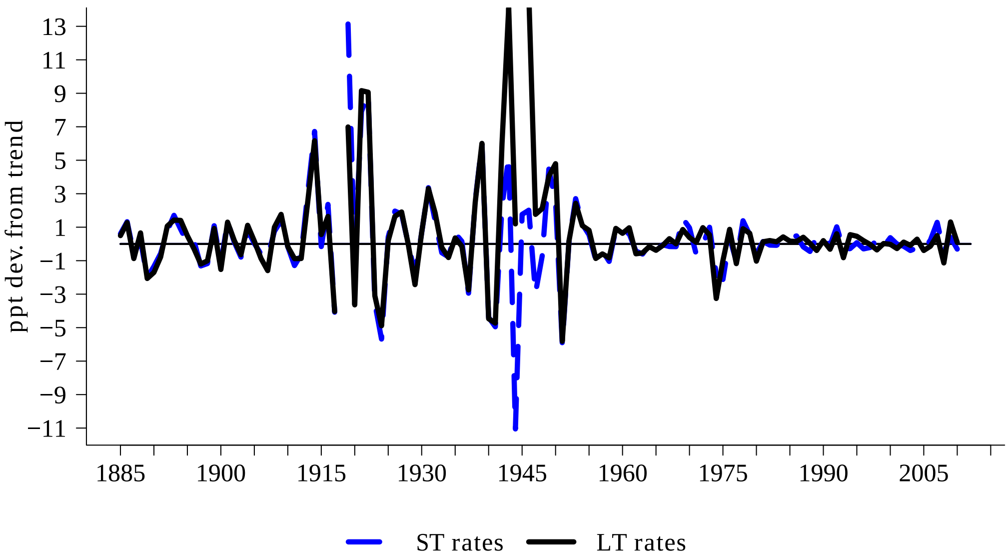
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 8-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.18: *Dividends and equity return premium, global average (2-8 year cycles)*



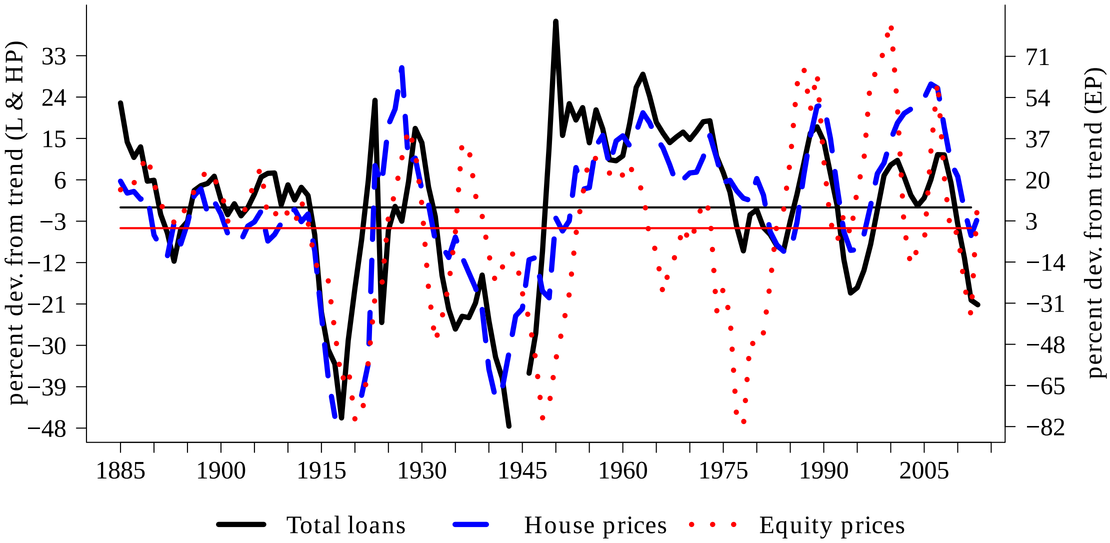
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 8-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.19: *Interest rates, global average (2-8 year cycles)*



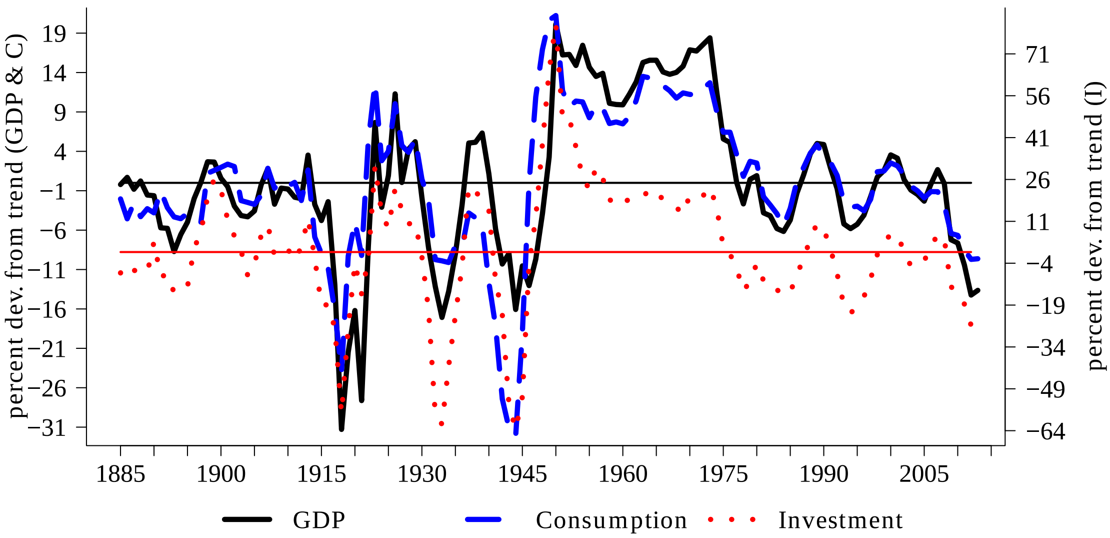
Notes: Global means. All series were detrended with a Baxter-King filter isolating cycles in the 2 to 8-year period range. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.20: *Financial cycles, global average (Hamilton filter)*



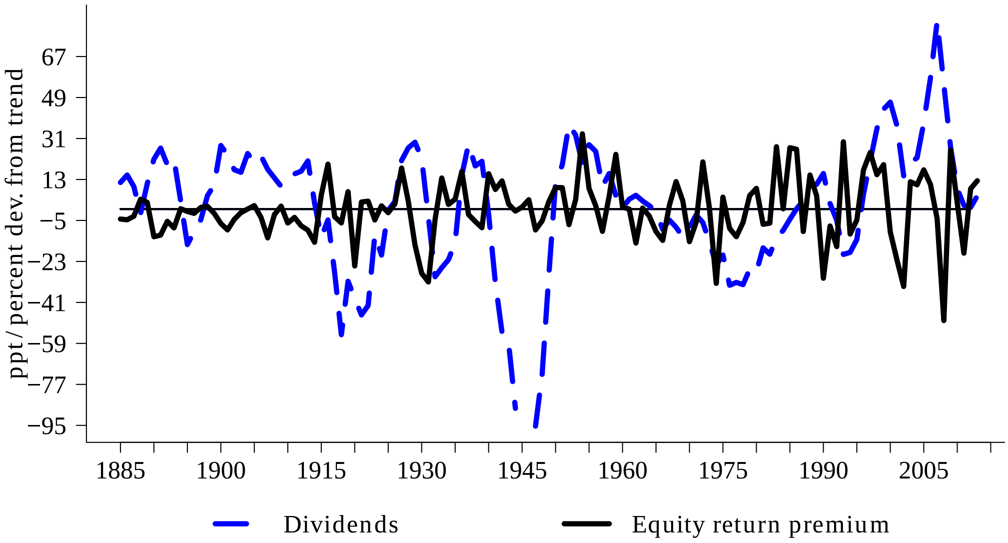
Notes: Global means. All series were detrended with the Hamilton filter, using lags five to eight. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.21: *Real cycles, global average (Hamilton filter)*



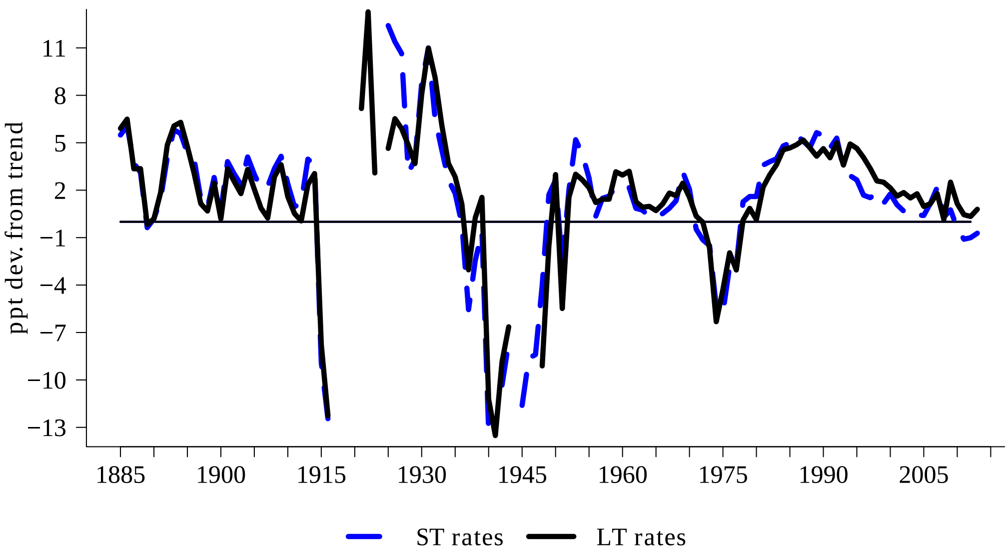
Notes: Global means. All series were detrended with the Hamilton filter, using lags five to eight. Outliers have been dropped from the graph in order to simplify the graphical exposition.

Figure 3.22: *Dividends and equity return premium, global average (Hamilton filter)*



Notes: Global means. All series were detrended with the Hamilton filter, using lags five to eight. Outliers have been dropped from the graph in order to simplify the graphical exposition.

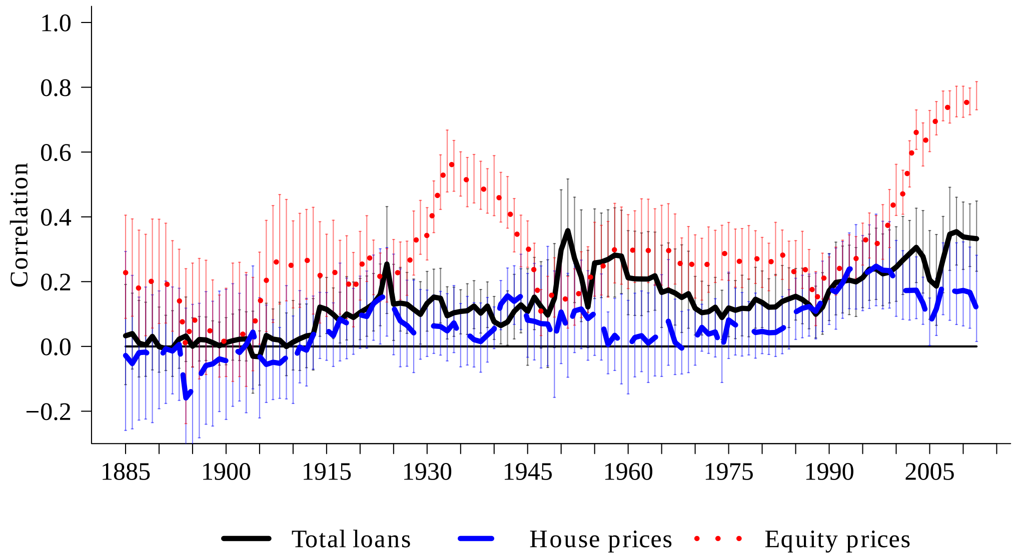
Figure 3.23: *Interest rates, global average (Hamilton filter)*



Notes: Global means. All series were detrended with the Hamilton filter, using lags five to eight. Outliers have been dropped from the graph in order to simplify the graphical exposition.

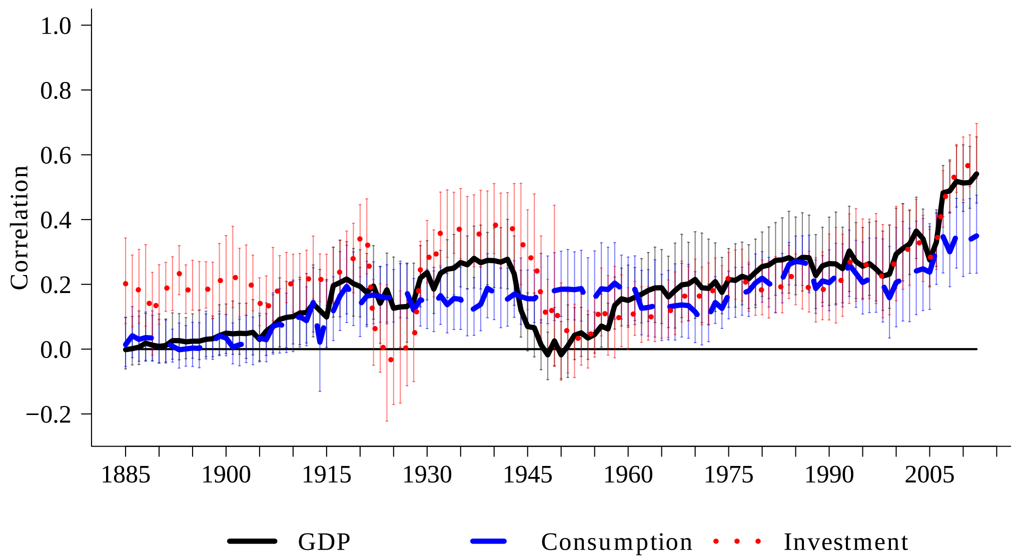
3.A.2. *Average bilateral correlations*

Figure 3.24: *Average bilateral financial cycle correlation (2-8 year cycles)*



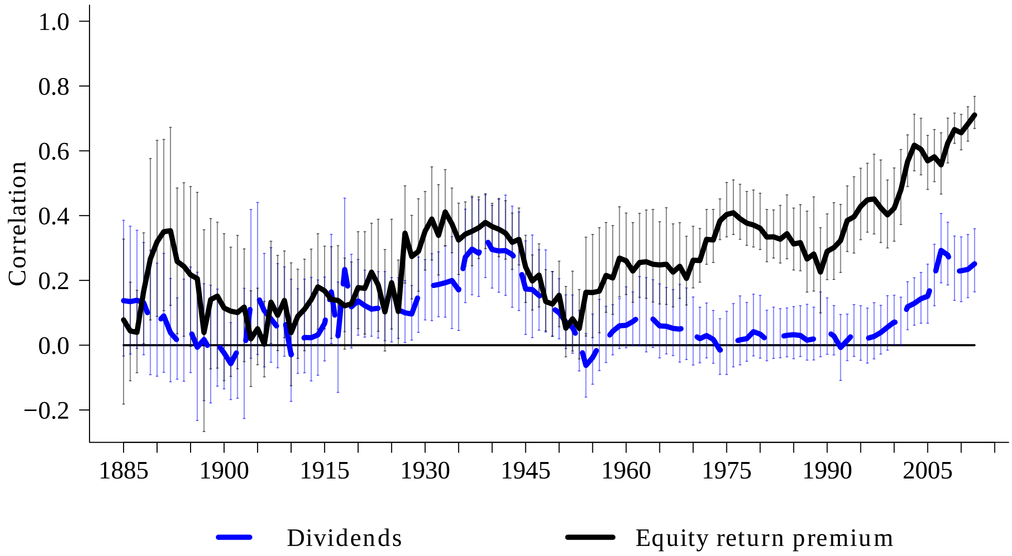
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 8-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.25: *Average bilateral real economy correlation (2-8 year cycles)*



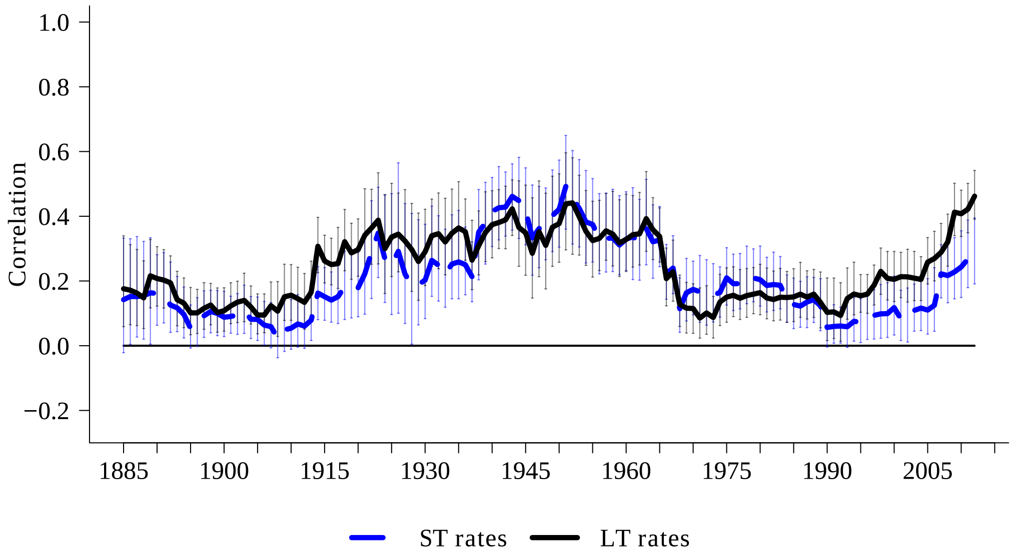
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 8-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.26: *Average bilateral dividend and equity premium correlation (2-8 year cycles)*



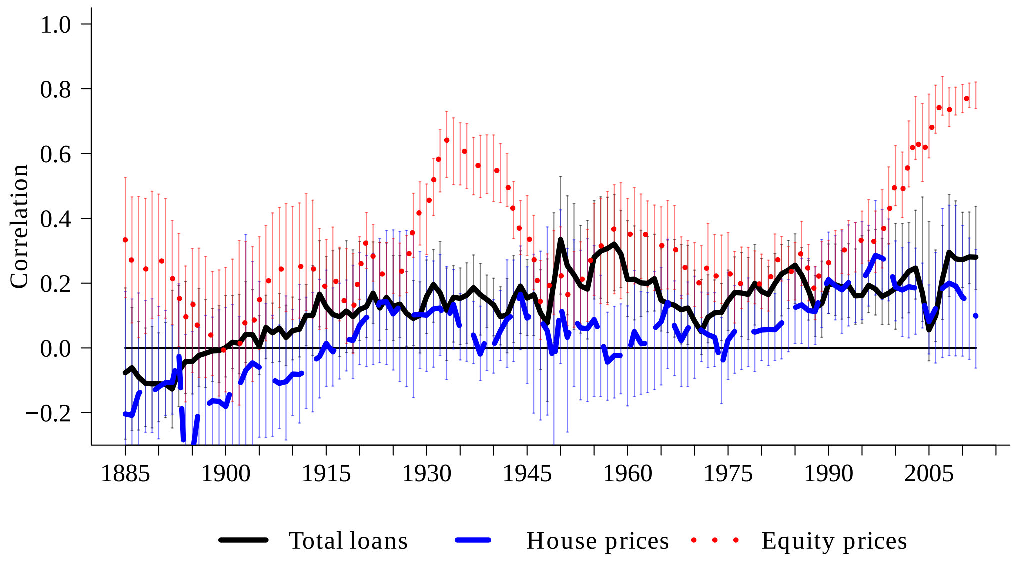
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 8-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.27: *Average bilateral interest rate correlation (2-8 year cycles)*



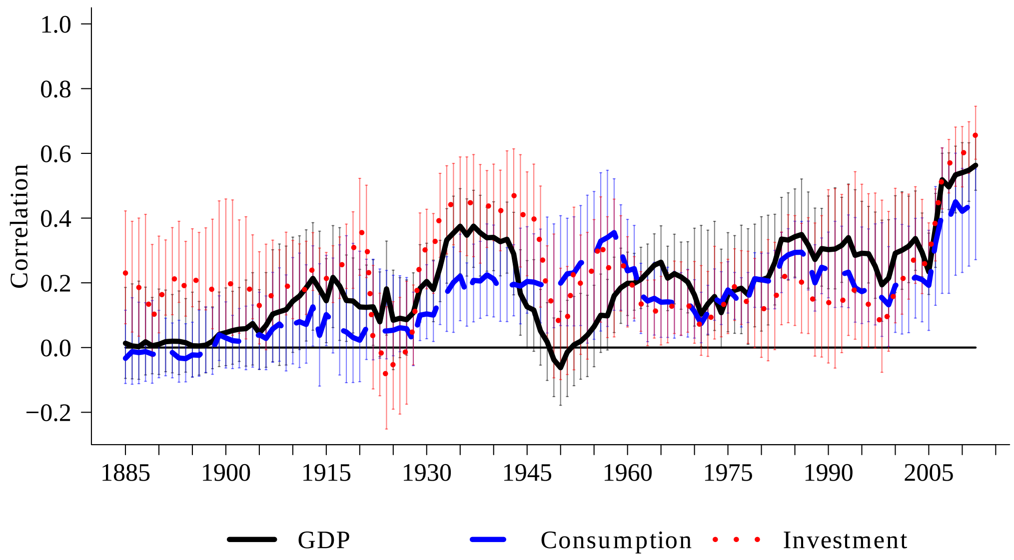
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 8-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.28: *GDP-weighted average bilateral financial cycle correlation (2-32 year cycles)*



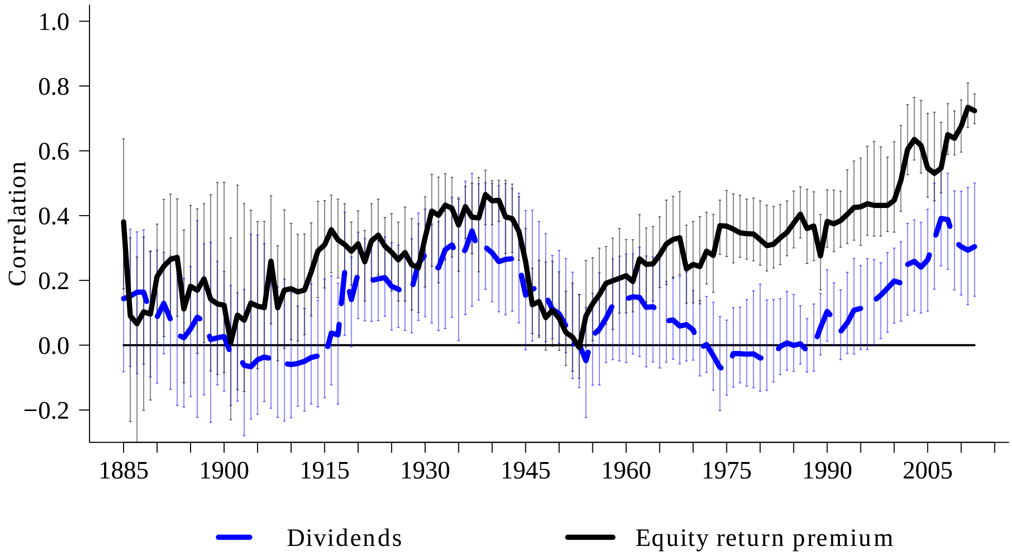
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.29: *GDP-weighted average bilateral real economy correlation (2-32 year cycles)*



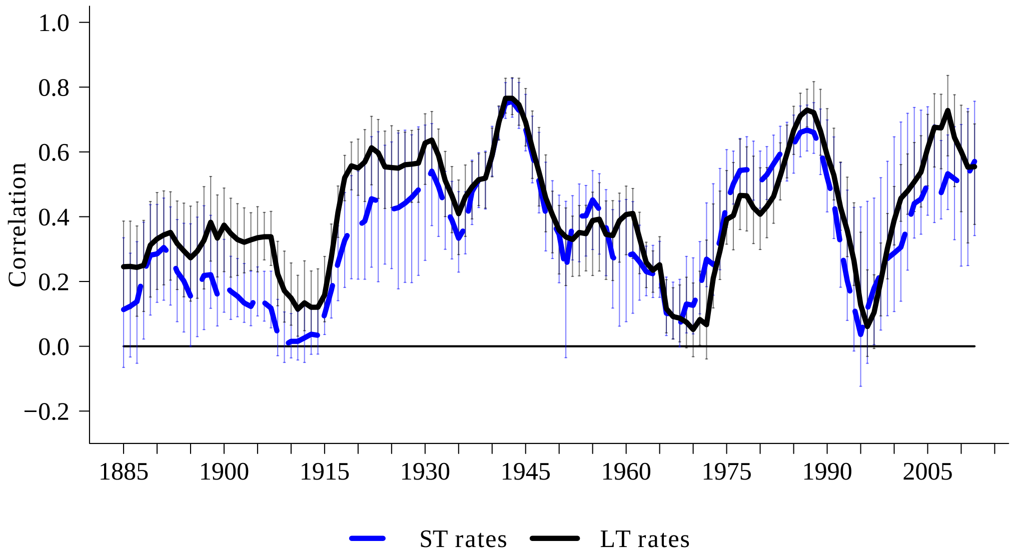
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.30: *GDP-weighted average bilateral dividend (2-32 year cycles) and equity premium correlation*



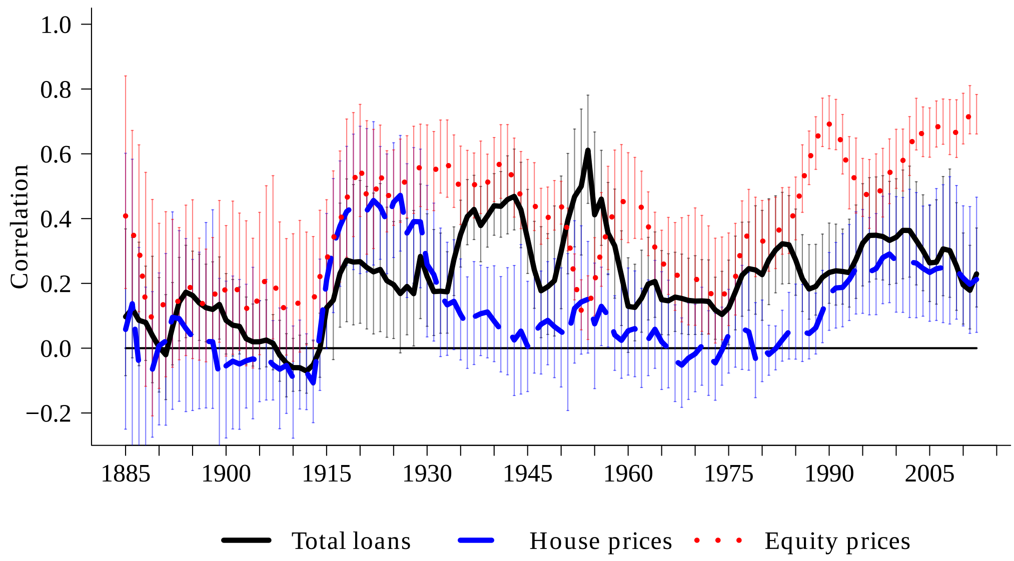
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Dividends: 2 to 32-year period Baxter-King detrended series. Equity return premium: Levels. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.31: *GDP-weighted average bilateral interest rate correlation*



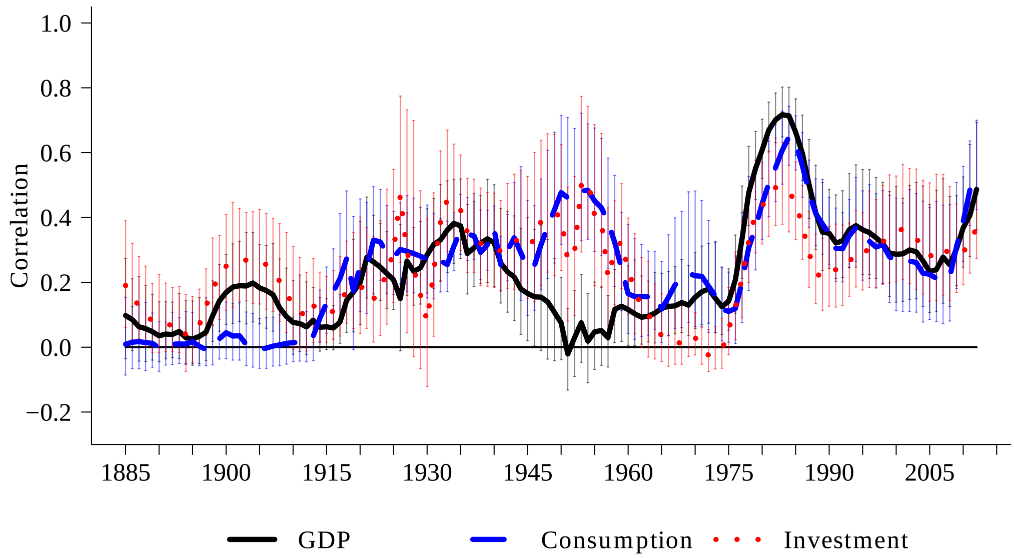
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Interest rates in levels. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.32: *Average bilateral financial cycle correlation (Hamilton filter)*



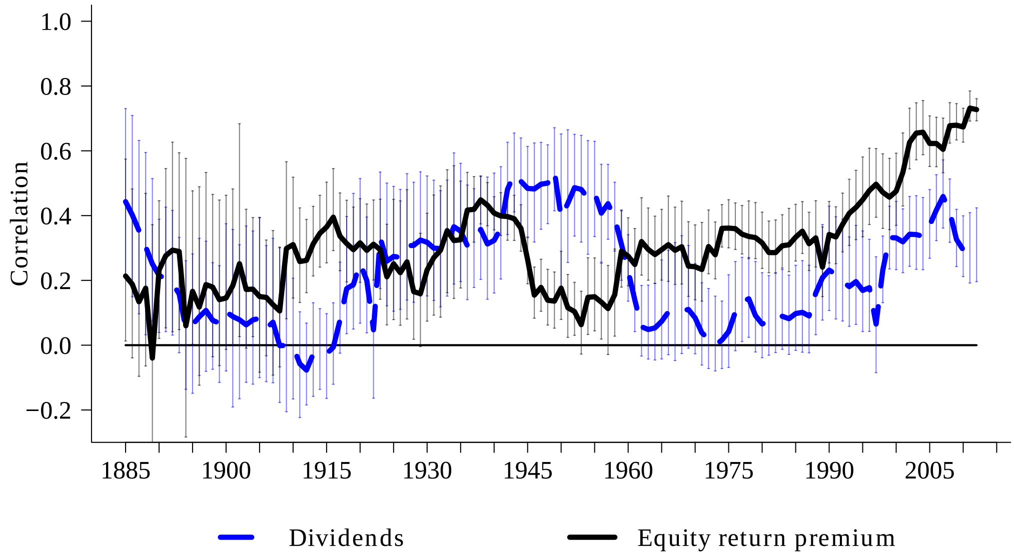
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Hamilton filter detrended series (using lags five to eight). Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.33: *Average bilateral real economy correlation (Hamilton filter)*



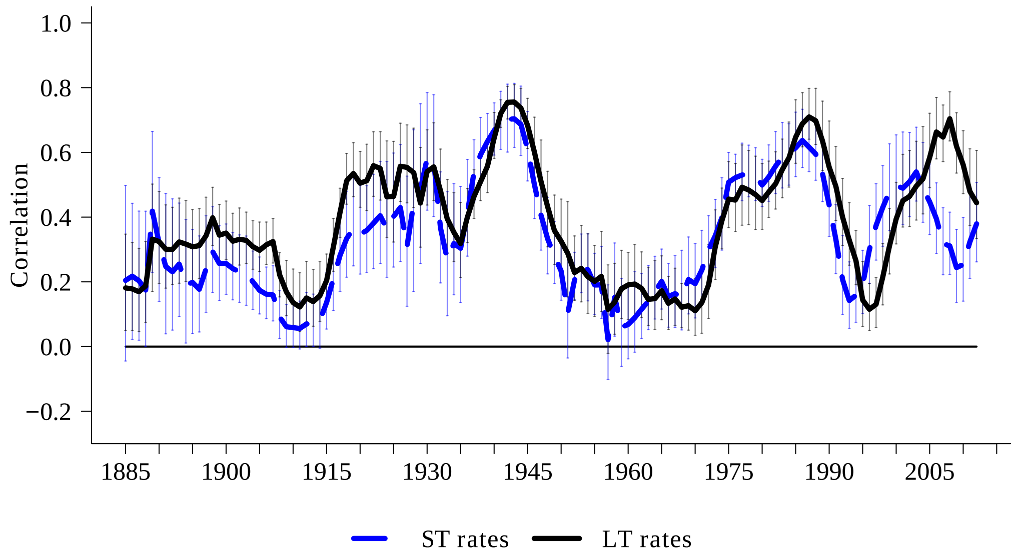
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Hamilton filter detrended series (using lags five to eight). Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.34: *Average bilateral dividend and equity premium correlation (Hamilton filter)*



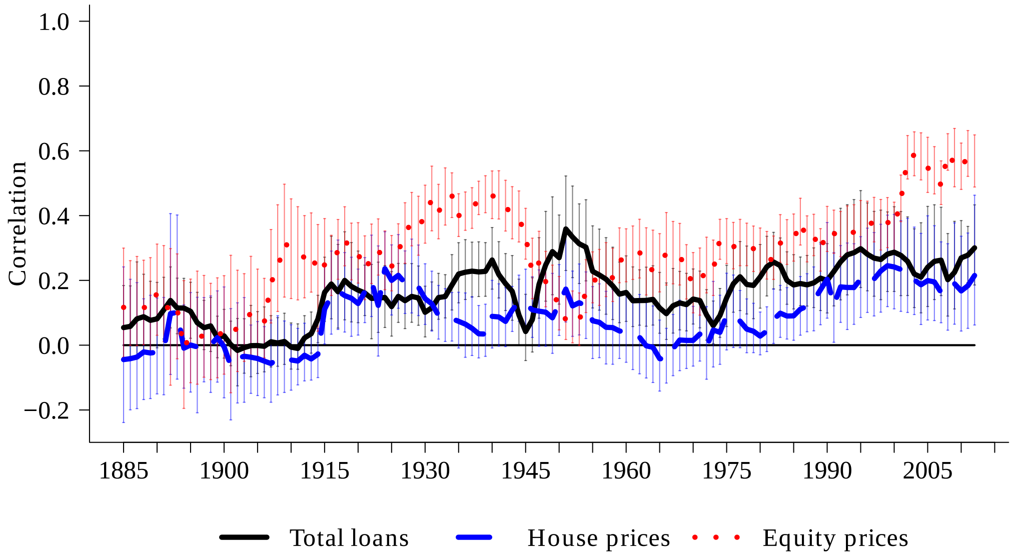
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Hamilton filter detrended series (using lags five to eight). Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.35: *Average bilateral interest rate correlation (Hamilton filter)*



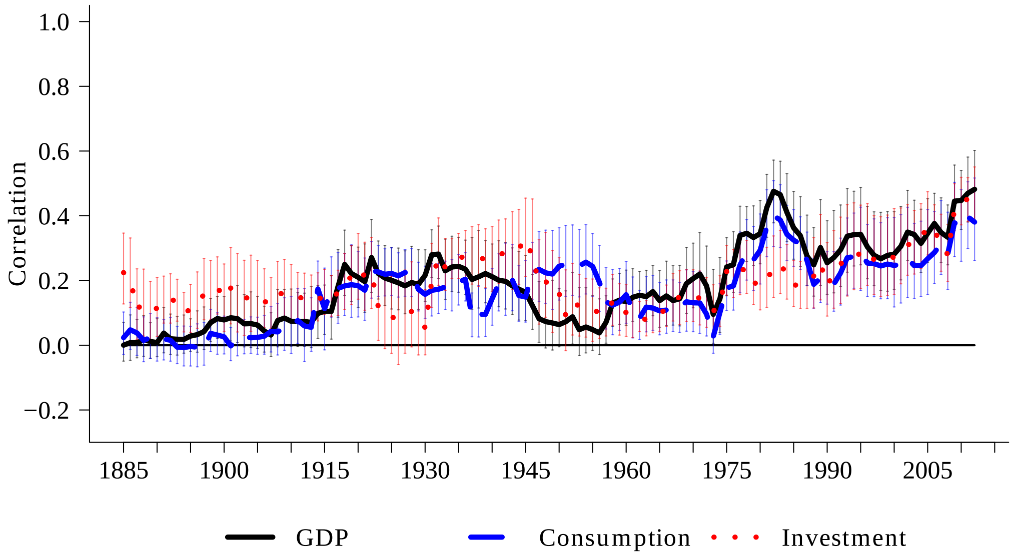
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Hamilton filter detrended series (using lags five to eight). Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.36: *Average bilateral financial cycle correlation (annual growth rates)*



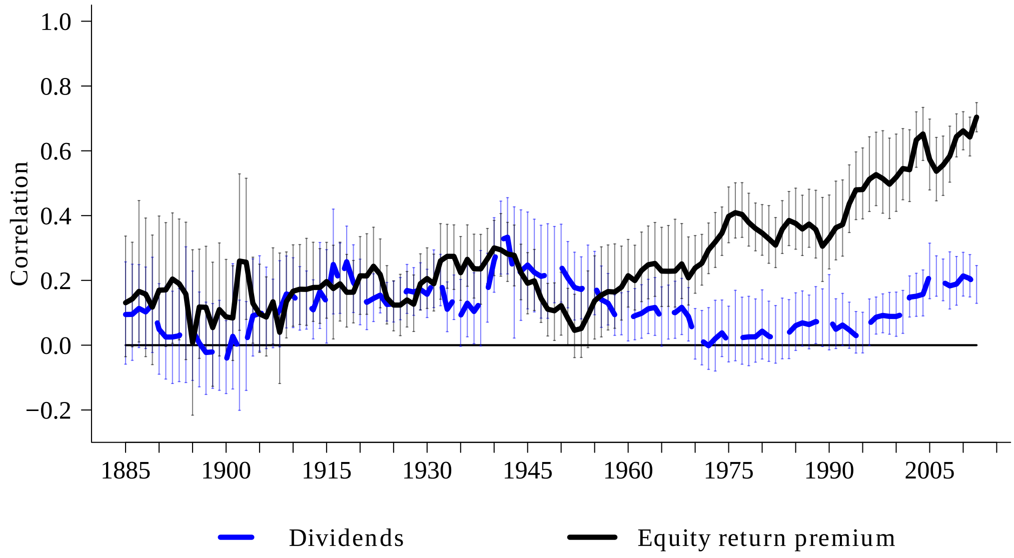
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. First differences (for rates) and growth rates for all other variables. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.37: *Average bilateral real economy correlation (annual growth rates)*



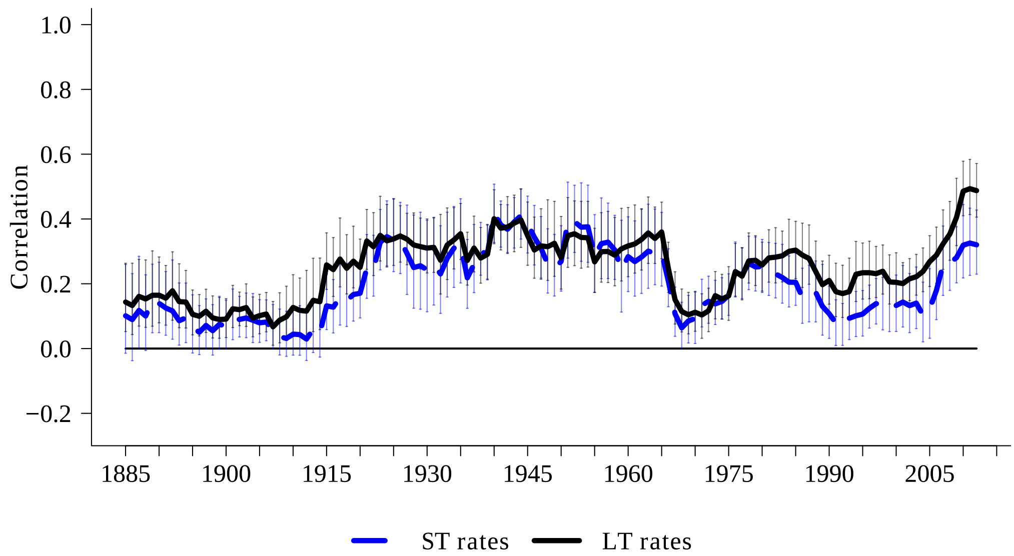
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. First differences (for rates) and growth rates for all other variables. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.38: *Average bilateral dividend and equity premium correlation (first differences)*



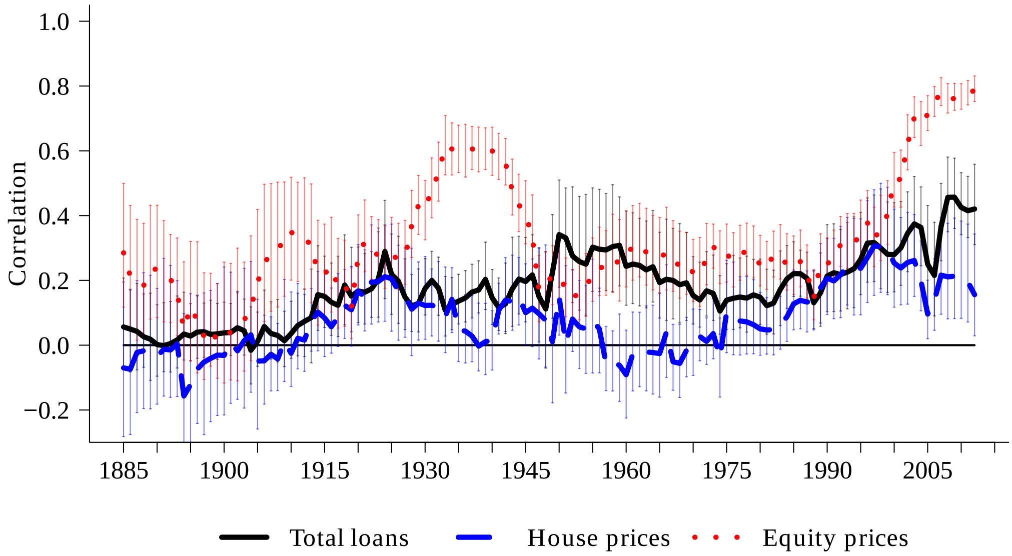
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. First differences (for rates) and growth rates for all other variables. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.39: *Average bilateral interest rate correlations (first differences)*



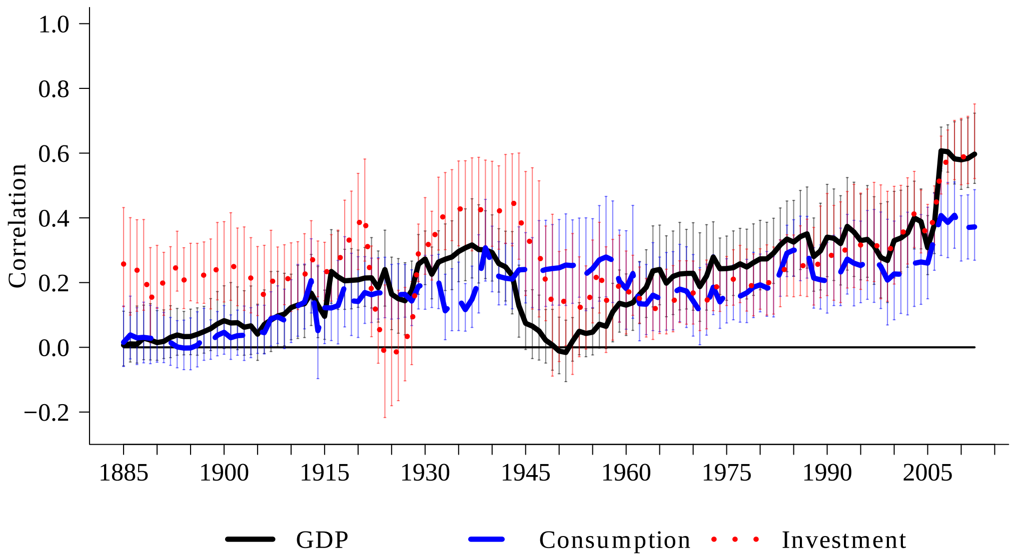
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. First differences (for rates) and growth rates for all other variables. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.40: *Average bilateral financial cycle correlation (Pearson correlation coefficient)*



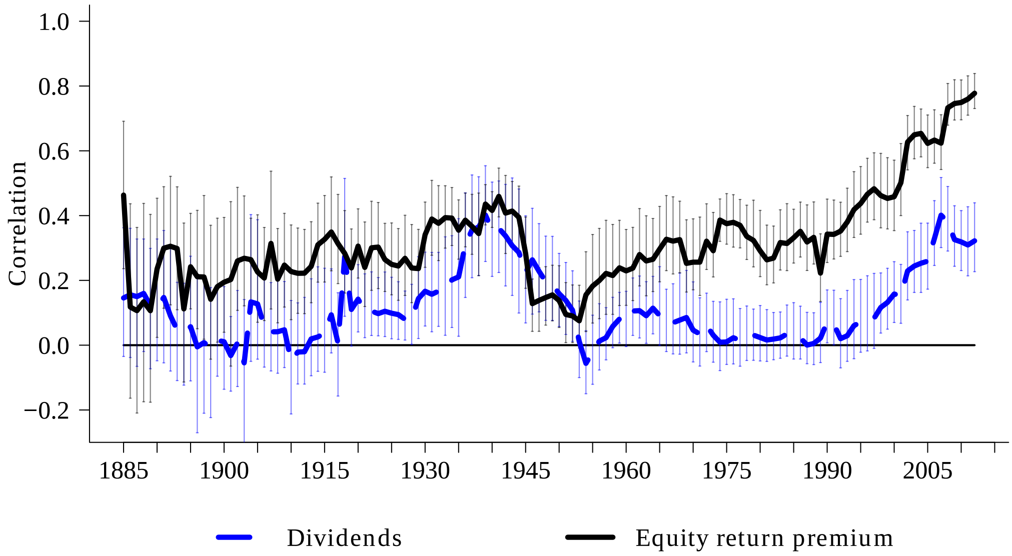
Notes: Pearson correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.41: *Average bilateral real economy correlation (Pearson correlation coefficient)*



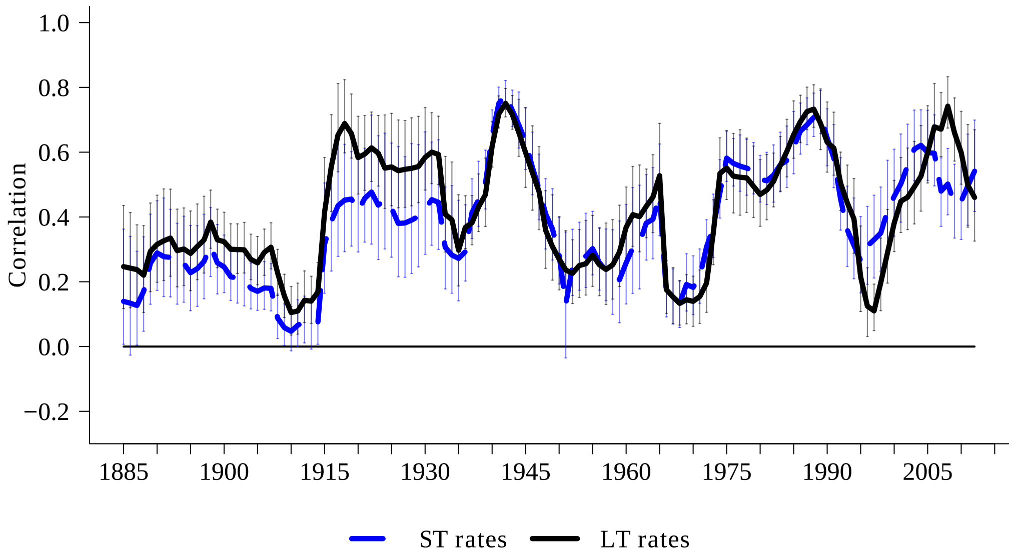
Notes: Pearson correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.42: *Average bilateral dividend and equity return premium correlations (Pearson correlation coefficient)*



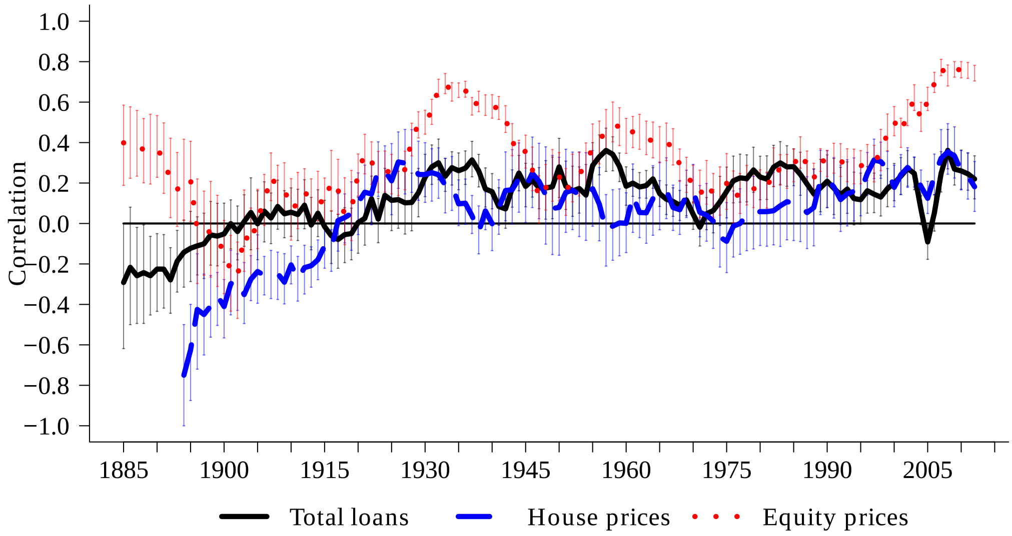
Notes: Pearson correlation coefficients based on 15-year rolling windows. Dividends: 2 to 32-year period Baxter-King detrended series. Equity return premium: Levels. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.43: *Average bilateral interest rate correlations (Pearson correlation coefficient)*



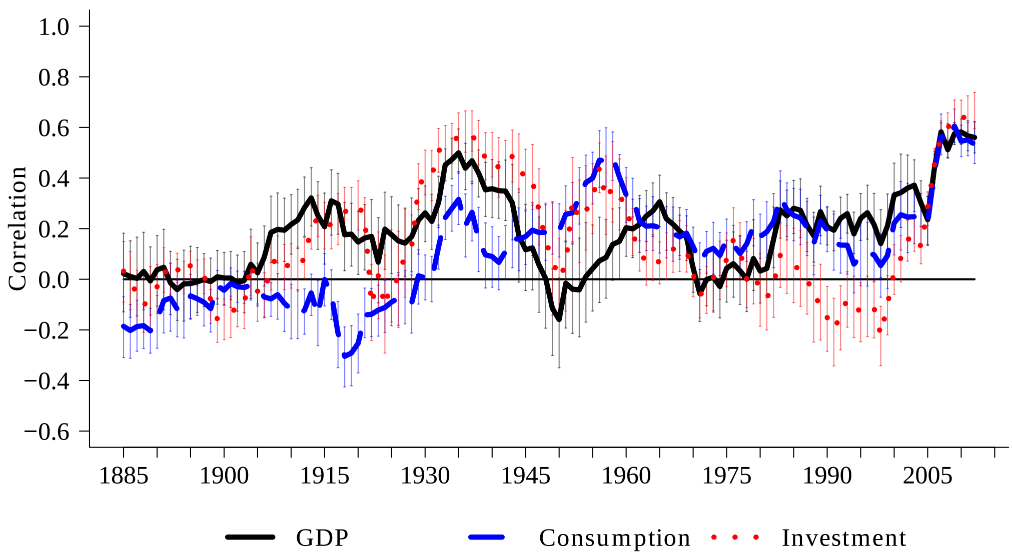
Notes: Pearson correlation coefficients based on 15-year rolling windows. Interest rates in levels. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.44: *Average bilateral financial cycle correlation (USA)*



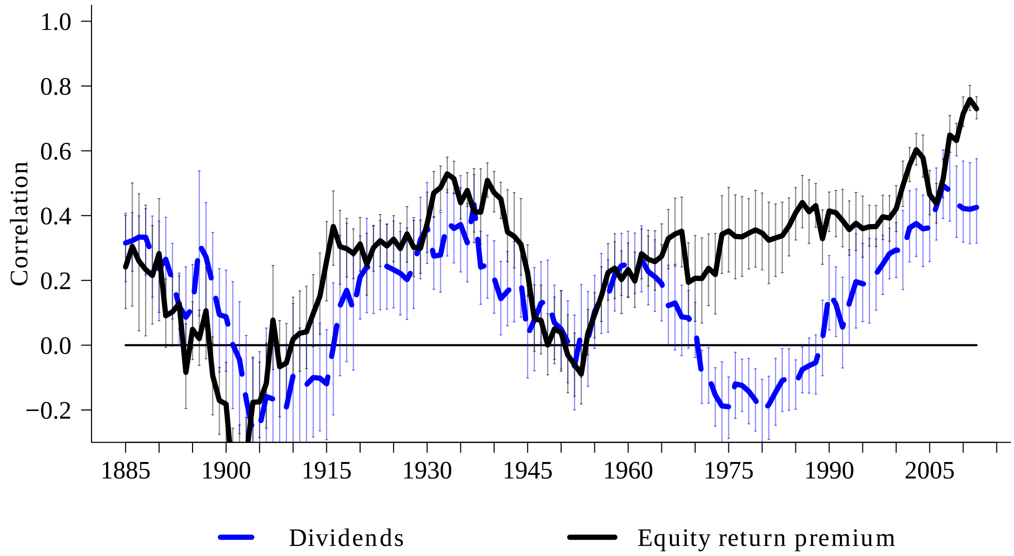
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.45: *Average bilateral real economy correlation (USA)*



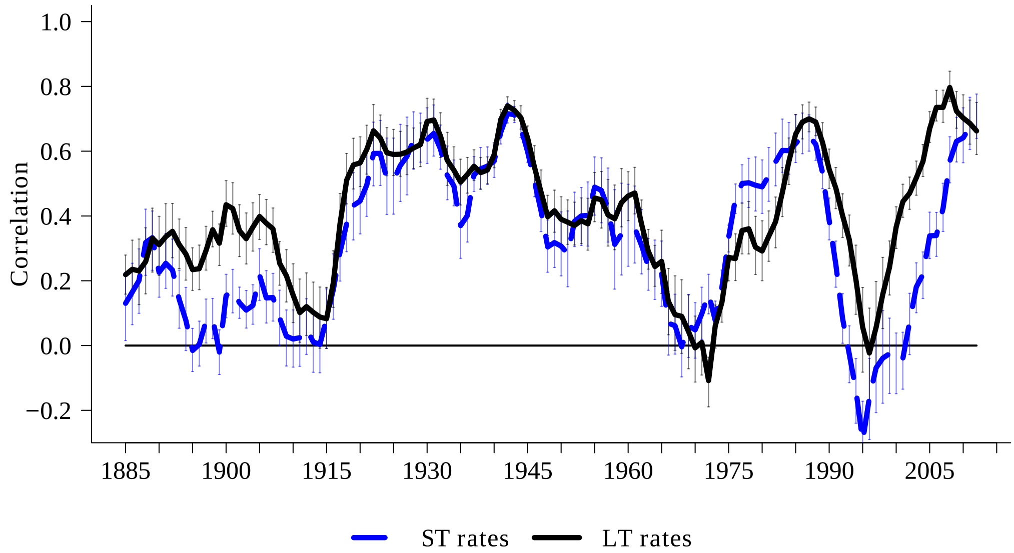
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. 2 to 32-year period Baxter-King detrended series. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.46: *Average bilateral dividend and equity return premium correlations (USA)*



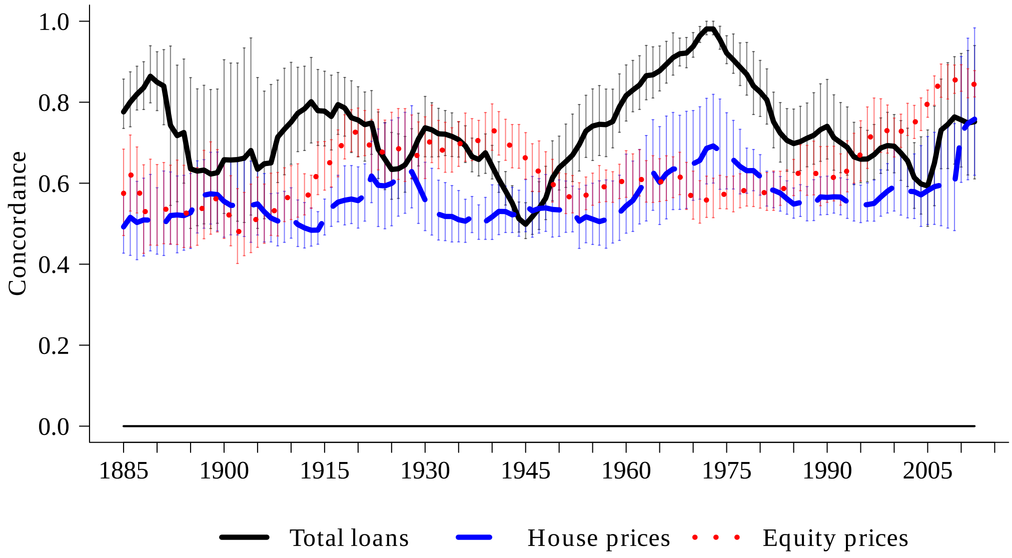
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Dividends: 2 to 32-year period Baxter-King detrended series. Equity return premium: Levels. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.47: *Average bilateral interest rate correlations (USA)*



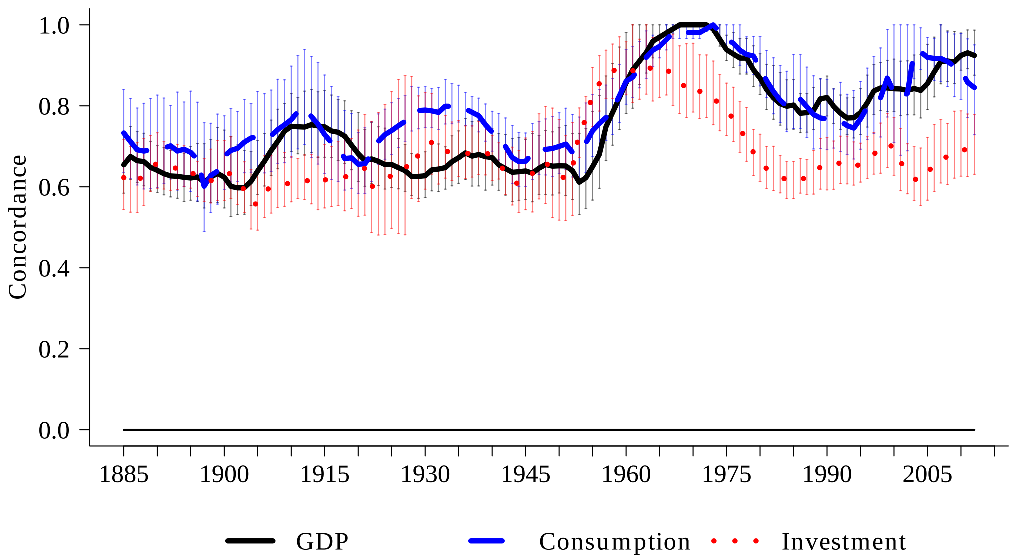
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Interest rates in levels. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.48: *Average bilateral financial cycle concordance*



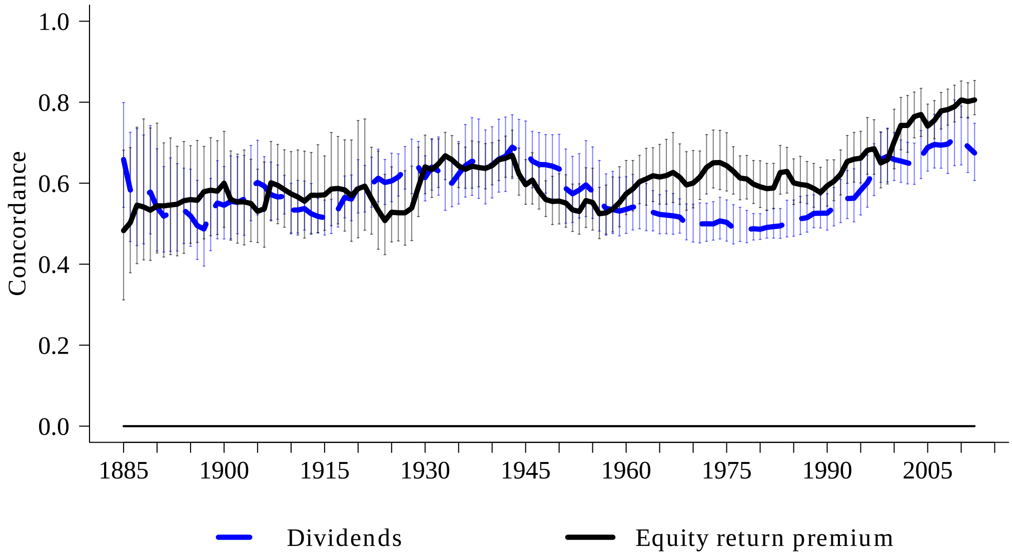
Notes: Concordance based on 15-year rolling windows. Peaks defined as highest values in +/-2 year window. Minimum phase length 2 years. Minimum cycle length 4 years. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.49: *Average bilateral real economy concordance*



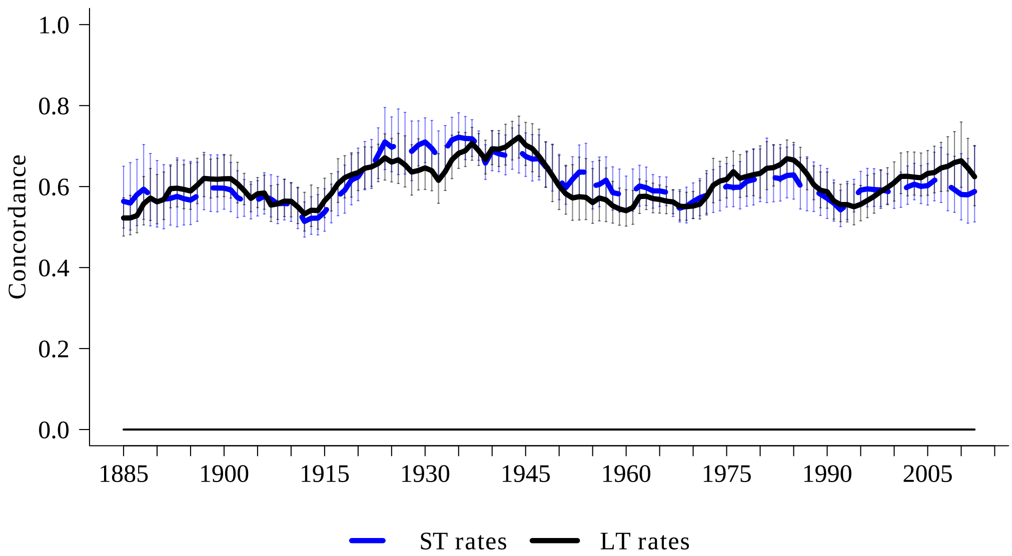
Notes: Concordance based on 15-year rolling windows. Peaks defined as highest values in +/-2 year window. Minimum phase length 2 years. Minimum cycle length 4 years. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.50: *Average bilateral dividend and equity return premium concordance*



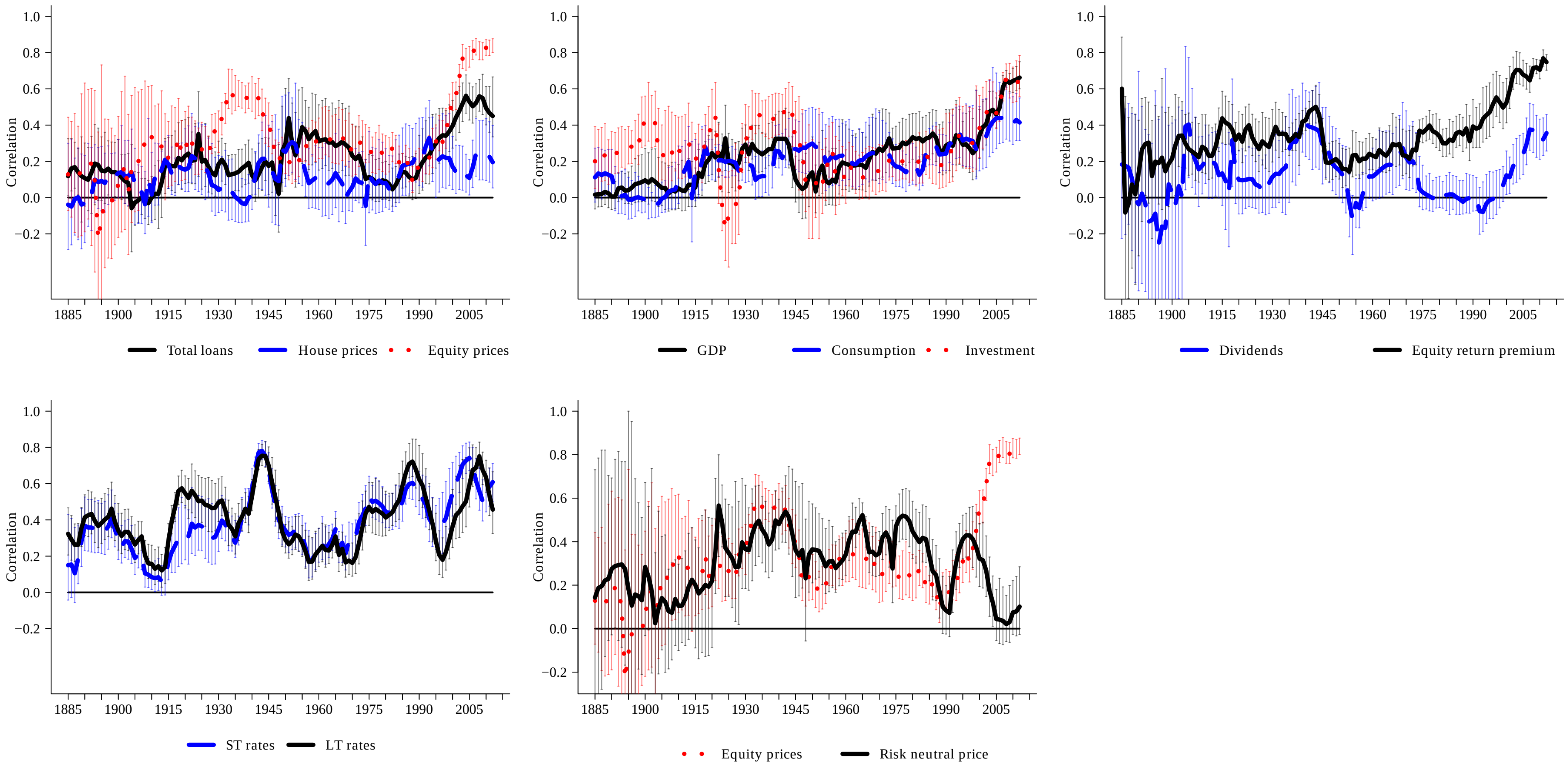
Notes: Concordance based on 15-year rolling windows. Peaks defined as highest values in +/-2 year window. Minimum phase length 2 years. Minimum cycle length 4 years. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.51: *Average bilateral interest rate concordance*



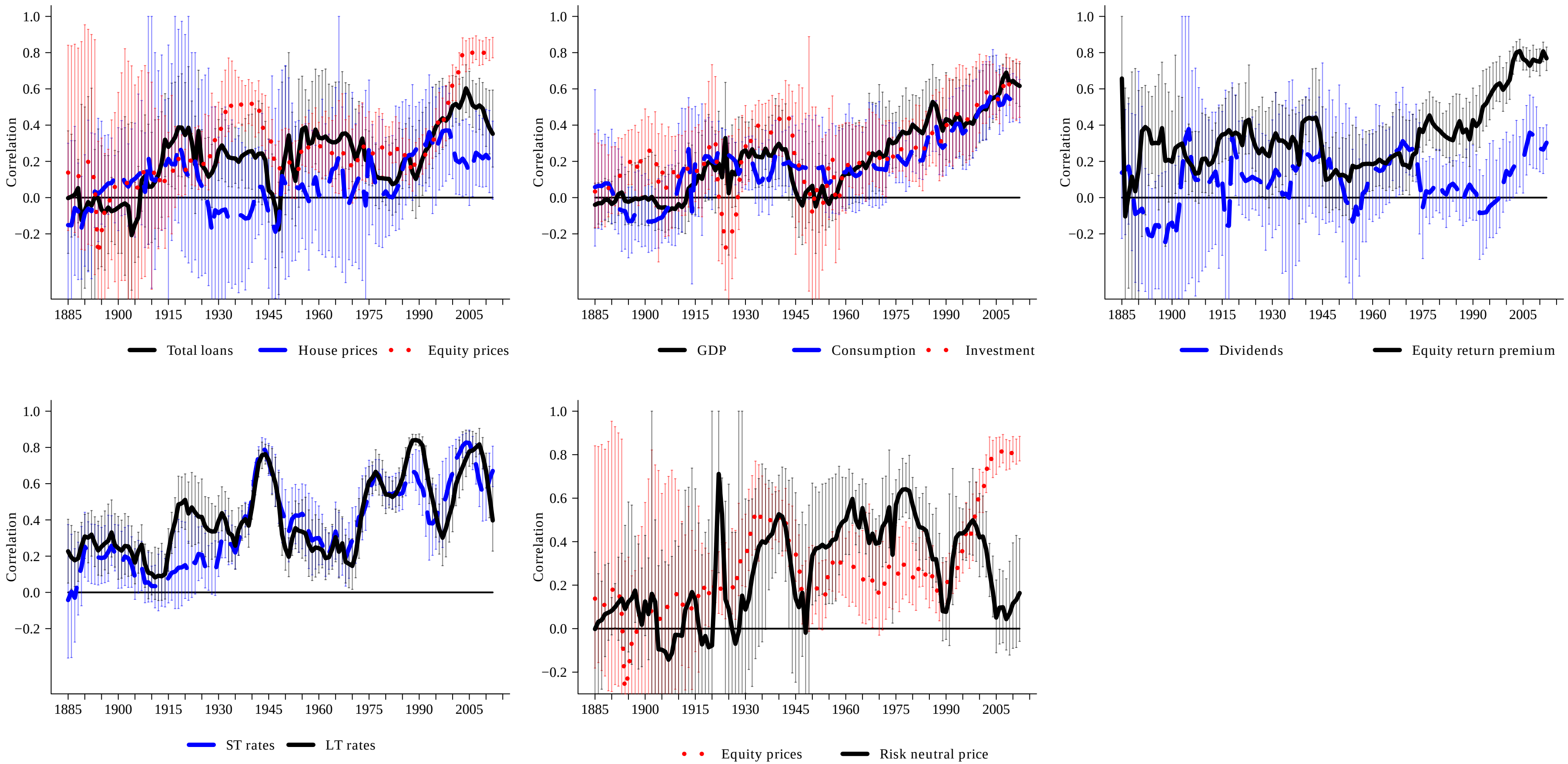
Notes: Concordance based on 15-year rolling windows. Peaks defined as highest values in +/-2 year window. Minimum phase length 2 years. Minimum cycle length 4 years. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.52: *Regional correlations: Europe*



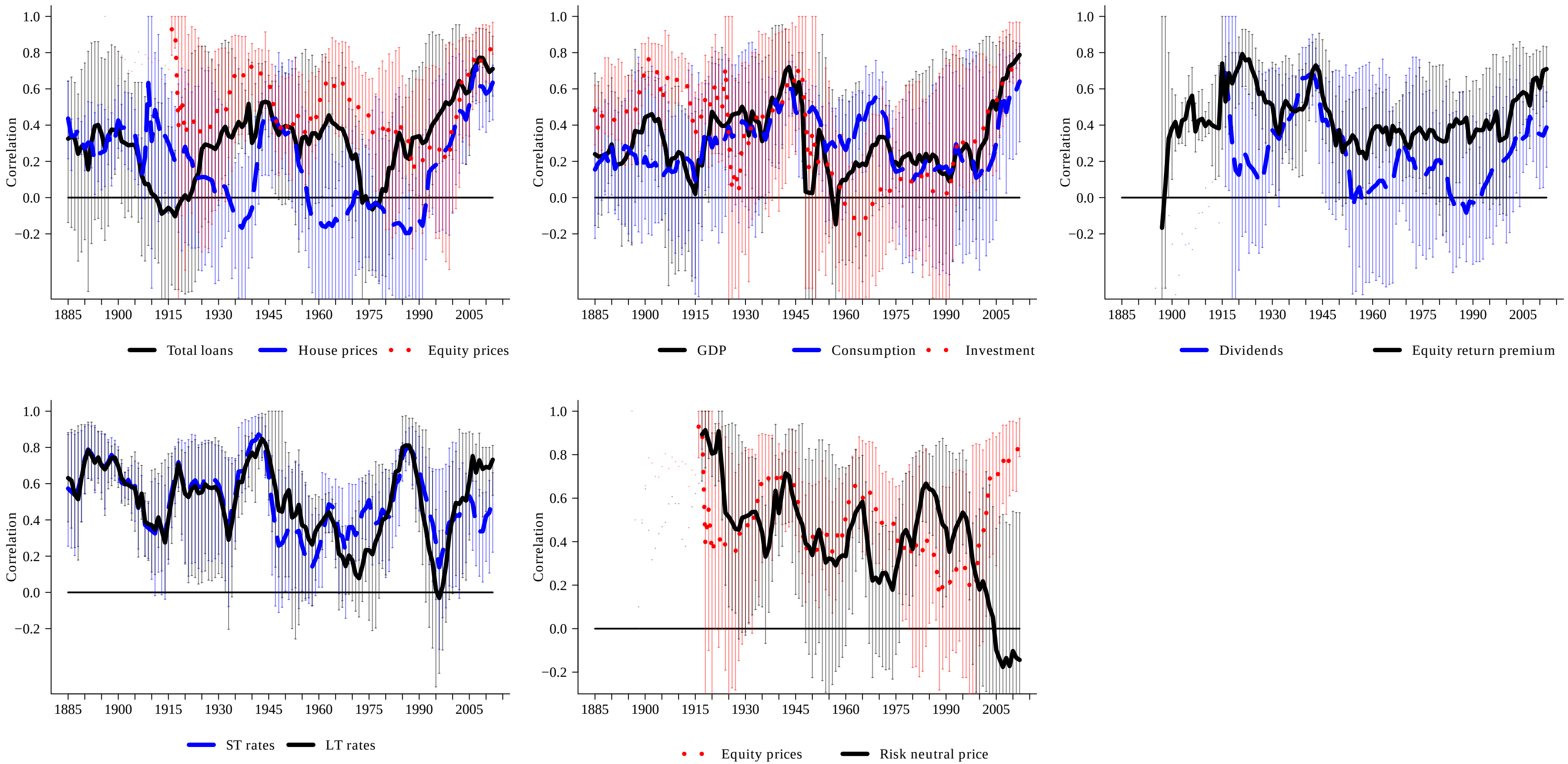
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.53: *Regional correlations: Euro area*



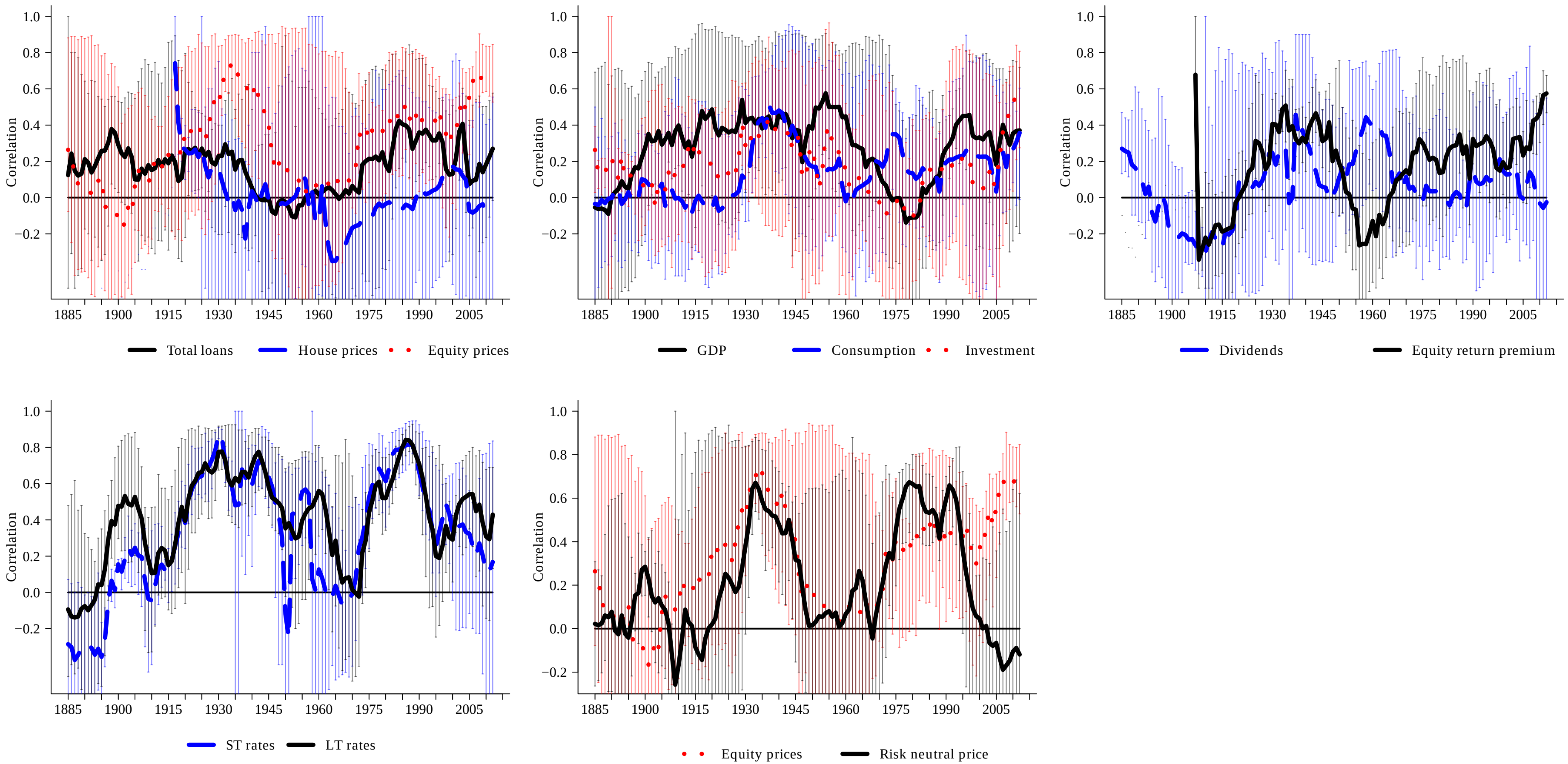
Notes: Spearman rank correlation coefficients based on 15-year rolling windows. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.54: *Regional correlations: Scandinavia*



Notes: Scandinavia: Denmark, Finland, Norway, and Sweden. Spearman rank correlation coefficients based on 15-year rolling windows. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

Figure 3.55: *Regional correlations: Pacific*



Notes: Pacific region: Australia, Canada, Japan, and U.S.A. Spearman rank correlation coefficients based on 15-year rolling windows. Bars – 95% cross-sectionally block-bootstrapped confidence bands.

3.A.3. *Equity return premium covariance decomposition*

This section decomposes equity return premiums through a vector autoregression (VAR) decomposition in the spirit of Campbell (1991). The advantage of such decompositions over the comovement analyses presented so far is that they explicitly model investor expectations, and thus do not require the equalization of ex ante expected values with ex post realized ones. A recent example for such a decomposition based on the long-run data we use is Kuvshinov (n.d.). In particular, we build on the two-country decomposition suggested by Ammer and Mei (1996). This approach attributes unexpected fluctuations in the current equity return premium of country i ($\tilde{e}^i_{t+1}$) to news about future discounted dividends, risk-free rates and equity return premiums.

The return premium model

Starting from the log gross equity return definition

$$h_{t+1} = log(P_{t+1} + D_{t+1}) - log(P_t), \tag{3.A.1}$$

where P denotes the equity price and D the dividend paid. A first order Taylor approximation yields

$$h_{t+1} \approx \delta_t - \rho\delta_{t+1} + \Delta d_{t+1} + k, \tag{3.A.2}$$

where Δd denotes the first difference of the log of the dividend payment D, δ is the dividend-price ratio, ρ is a (discount) factor smaller than 1 and k is a linearization constant (see Campbell and Shiller, 1988). Solving 3.A.2 forward[8], taking expectations and plugging the resulting expectation equations for δ_t and δ_{t+1} back into 3.A.2 results in the following expression for the unexpected change in the log real return on equity:

$$h_{t+1} - E_t h_{t+1} = (E_{t+1} - E_t)\left[\sum_{k=0}^{\infty}\rho^k \Delta d_{t+1+k} - \sum_{k=1}^{\infty}\rho^k h_{t+1+k}\right], \tag{3.A.3}$$

where E_t is an expectation operator denoting expectations formed on the basis of information available through t. Put in terms of equity return premiums $e_{t+1} := h_{t+1} - r_{t+1}$, where r denotes the log real interest rate, equation 3.A.3 can be rewritten as

$$e_{t+1} - E_t e_{t+1} = (E_{t+1} - E_t)\left[\sum_{k=0}^{\infty}\rho^k \Delta d_{t+1+k} - \sum_{k=0}^{\infty}\rho^k r_{t+1+k} - \sum_{k=1}^{\infty}\rho^k e_{t+1+k}\right], \tag{3.A.4}$$

or more compactly, for any country i

$$\tilde{e}^i_{t+1} = \tilde{e}^i_{d,t+1} - \tilde{e}^i_{r,t+1} - \tilde{e}^i_{e,t+1}. \tag{3.A.5}$$

The general intuition behind equation 3.A.5 is that innovations in the equity return premium

[8]Note the assumption of the transversality condition $lim_{k\to\infty}\rho^k\delta_{t+k} = 0$, as well as $E_t\delta_t = \delta_t$.

of country i can be decomposed into news about the discounted sum of future dividend streams, news about the discounted sum of future risk-free real interest rates, and news about the discounted sum of future equity return premiums. Thus, if the equity return premium increases, this is either due to news about higher future dividends, lower future risk-free rates or lower future return premiums.

Consider the same decomposition for another country j. In order to render real equity returns in j comparable to those in i it is necessary to introduce a real exchange rate term $\tilde{e}_{q,t+1}$:

$$\tilde{e}^{j}_{t+1} = \tilde{e}^{j}_{d,t+1} - \tilde{e}^{j}_{r,t+1} - \tilde{e}^{j}_{e,t+1} - \tilde{e}^{j}_{q,t+1}, \tag{3.A.6}$$

where $\tilde{e}_{q,t+1} = (E_{t+1} - E_t)\sum_{k=0}^{\infty} \rho^k q_{t+1+k}$ denotes news about the sum of future discounted log real exchange rates.[9]

We are interested in characterizing the comovement of return premiums in countries i and j, $\tilde{e}^{i}_{t+1}$ and $\tilde{e}^{j}_{t+1}$. From equations 3.A.5 and 3.A.6 it follows that the covariance in equity return premiums $Cov(\tilde{e}^{i}, \tilde{e}^{j})$ can be decomposed as follows:

$$\begin{aligned} Cov(\tilde{e}^{i}, \tilde{e}^{j}) = {} & Cov(\tilde{e}^{i}_{d}, \tilde{e}^{j}_{d}) - Cov(\tilde{e}^{i}_{d}, \tilde{e}^{j}_{r}) - Cov(\tilde{e}^{i}_{d}, \tilde{e}^{j}_{e}) - Cov(\tilde{e}^{i}_{d}, \tilde{e}^{j}_{q}) \\ & - Cov(\tilde{e}^{i}_{r}, \tilde{e}^{j}_{d}) + Cov(\tilde{e}^{i}_{r}, \tilde{e}^{j}_{r}) + Cov(\tilde{e}^{i}_{r}, \tilde{e}^{j}_{e}) + Cov(\tilde{e}^{i}_{r}, \tilde{e}^{j}_{q}) \\ & - Cov(\tilde{e}^{i}_{e}, \tilde{e}^{j}_{d}) + Cov(\tilde{e}^{i}_{e}, \tilde{e}^{j}_{r}) + Cov(\tilde{e}^{i}_{e}, \tilde{e}^{j}_{e}) + Cov(\tilde{e}^{i}_{e}, \tilde{e}^{j}_{q}). \end{aligned} \tag{3.A.7}$$

This decomposition allows us to analyze whether the rise in equity return premium comovement was due to a rise in the comovement of dividend news $Cov(\tilde{e}^{i}_{d}, \tilde{e}^{j}_{d})$, risk-free rate news $Cov(\tilde{e}^{i}_{r}\tilde{e}^{j}_{r})$, or return premium news $Cov(\tilde{e}^{i}_{e}, \tilde{e}^{j}_{e})$.

Note, that in contrast to the comovement analyses presented in the main text, which have looked at equity prices, the covariance analysis presented here directly looks at the comovement in equity return premiums. The results of the two approaches are comparable in that they both indicate the extent to which international comovement in equities can be accounted for by fundamentals – dividends and risk-free rates – and how much must be attributed to other factors – risk appetite, or news about future return premiums.

The VAR model

In order to compute the variance decomposition 3.A.7 we need estimates of the various news terms in equations 3.A.5 and 3.A.6. A VAR model serves this purpose. The assumption is that changes in expectations due to new information arriving between t and $t+1$ can be isolated through the VAR model. We estimate bilateral VARs on the basis of the following variables: log equity return premiums $e_{i,t}, e_{j,t}$, log real interest rates $r_{i,t}, r_{j,t}$, dividend-price ratios $\delta_{i,t}, \delta_{j,t}$

[9] Note that while the general setup follows Ammer and Mei (1996), the term $\tilde{e}_{r,t+1}$ refers to foreign log real interest rates here, instead of domestic log real rates as in Ammer and Mei (1996). This change allows us to investigate the relative importance of monetary policy synchronization in the synchronicity of equity return premiums.

and the first differences of the log bilateral real exchange rate Δq_t. Collecting these variables in the vector $\mathbf{z_t} = \begin{pmatrix} e_t^i & r_t^i & \delta_t^i & e_t^j & r_t^j & \delta_t^j & q_t^j \end{pmatrix}^T$ the VAR model for $\boldsymbol{z_{t+1}}$ in companion form is

$$\boldsymbol{z_{t+1}} = \boldsymbol{A z_t} + \boldsymbol{\epsilon_{t+1}}, \tag{3.A.8}$$

where $\boldsymbol{A}$ is the VAR parameter matrix and $\boldsymbol{\epsilon}$ contains the error terms. The inclusion of variables from countries i and j enables us to study the linkage between both countries.

The equity return premium model summarized by equations 3.A.5 and 3.A.6 imposes a tight set of cross-equation restrictions on the VAR. On the basis of these and the estimated VAR we compute each of the news components in equations 3.A.5 and 3.A.6 for each bilateral country-pair i, j. For this purpose we define picking vectors $\boldsymbol{g_k}$ that select the relevant rows from the VAR system.

$$\tilde{\boldsymbol{e}}^{\boldsymbol{m}}_{\boldsymbol{t+1}} = \boldsymbol{g_1^m} \boldsymbol{\epsilon_{t+1}}, \quad m = i, j \tag{3.A.9}$$

$$\tilde{\boldsymbol{e}}^{\boldsymbol{m}}_{\boldsymbol{e,t+1}} = \boldsymbol{g_1^m} \rho_m \boldsymbol{A}(\boldsymbol{I} - \rho_m \boldsymbol{A})^{-1} \boldsymbol{\epsilon_{t+1}}, \quad m = i, j \tag{3.A.10}$$

$$\tilde{\boldsymbol{e}}^{\boldsymbol{m}}_{\boldsymbol{r,t+1}} = \boldsymbol{g_2^m} (\boldsymbol{I} - \rho_m \boldsymbol{A})^{-1} \boldsymbol{\epsilon_{t+1}}, \quad m = i, j \tag{3.A.11}$$

$$\tilde{\boldsymbol{e}}^{\boldsymbol{j}}_{\boldsymbol{q,t+1}} = \boldsymbol{g_3^j} (\boldsymbol{I} - \rho_j \boldsymbol{A})^{-1} \boldsymbol{\epsilon_{t+1}} \tag{3.A.12}$$

$$\tilde{\boldsymbol{e}}^{\boldsymbol{i}}_{\boldsymbol{d,t+1}} = \tilde{\boldsymbol{e}}^{\boldsymbol{i}}_{\boldsymbol{t+1}} + \tilde{\boldsymbol{e}}^{\boldsymbol{i}}_{\boldsymbol{r,t+1}} + \tilde{\boldsymbol{e}}^{\boldsymbol{i}}_{\boldsymbol{e,t+1}} \tag{3.A.13}$$

$$\tilde{\boldsymbol{e}}^{\boldsymbol{j}}_{\boldsymbol{d,t+1}} = \tilde{\boldsymbol{e}}^{\boldsymbol{j}}_{\boldsymbol{t+1}} + \tilde{\boldsymbol{e}}^{\boldsymbol{j}}_{\boldsymbol{r,t+1}} + \tilde{\boldsymbol{e}}^{\boldsymbol{j}}_{\boldsymbol{e,t+1}} + \tilde{\boldsymbol{e}}^{\boldsymbol{j}}_{\boldsymbol{q,t+1}} \tag{3.A.14}$$

We set ρ to 0.96.[10] We can use the thus calculated news components in order to determine whether correlated dividend news ($\tilde{e}_d$), monetary policy news ($\tilde{e}_r$) or news about future equity return premiums ($\tilde{e}_e$) have historically been most important in driving the comovement in international equity return premiums.[11]

Covariance decomposition

Table 3.6 shows the covariance decomposition for the full sample, a pre-WW2 sample, a post-WW2 sample, as well as a post-1980 sample zooming in on the period of high equity price synchronization. The top row states the equity return premium covariance in our sample, and all following rows state the median bilateral component-covariances.

Clearly equity return premium covariance has increased over time, from 1.61 in the pre-WW2 sample to 1.99 in the post-WW2 sample, and 3.48 in the post-1980 sample. Among its components, dividend news covariance is the largest. However, dividend covariance has neither increased, nor decreased substantially over time. One covariance component that

[10] This value is directly gleaned from the data according to $\rho_i = (1 + exp(\overline{\delta_i}))$, with $\overline{\delta_i}$ denoting the mean of country i's log dividend-price ratio. For our annual data the values for ρ concentrate around 0.96.

[11] All bilateral VARs have been estimated with one lag, which is our preferred lag order given the relatively short time span covered by the subsamples we are interested in.

Table 3.6: *Decomposition of the covariance in equity return premiums*

	Full sample	Pre-WW2	Post-WW2	Post-1980
Cov(equity return premiums)	1.47	1.61	1.99	3.48
Cov(dividends)	**1.58**	**1.42**	**1.36**	**1.56**
-Cov(dividends, risk-free rate)	**-0.69**	-0.36	**-0.27**	0.1
-Cov(dividends, future return)	0.18	**-0.44**	**0.41**	0.1
-Cov(dividends, real exchange rate)	0.05	0.16	0.03	0.03
-Cov(risk-free rate, dividends)	**-0.52**	-0.46	**-0.2**	0.13
Cov(risk-free rates)	**0.9**	**0.54**	**0.34**	**0.27**
Cov(risk-free rate, future return)	-0.01	-0.07	-0.02	**-0.28**
Cov(risk-free rate, real exchange rate)	0	0.14	-0.03	-0.01
Cov(future return, risk-free rate)	-0.21	0.32	**-0.29**	0.01
-Cov(future return, dividends)	-0.01	0.01	0.1	**0.4**
Cov(future returns)	**0.28**	**0.52**	**0.6**	**1.23**
Cov(future return, real exchange rate)	-0.08	-0.16	-0.04	-0.06

Notes: Bold type – 95% significance-level based on cross-sectionally block-bootstrapped confidence bands. All covariances have been rescaled by a factor of 100. Median of bilateral covariances.

clearly increases over time is the covariance in news about future return premiums, which roughly doubles in size in the post-1980 sample.

Covariance in risk-free rate news exhibits a downward trend over time. This is consistent with many countries moving towards a floating exchange rate regime after the end of the Bretton Woods system of fixed exchange rates. As a consequence international risk-free rate covariance explains little of the covariance in return premiums after 1980. Finally, an important reason for the overall increase in equity return premiums is the decrease in various cross-variance terms, such as the covariance between dividends and risk-free rates.

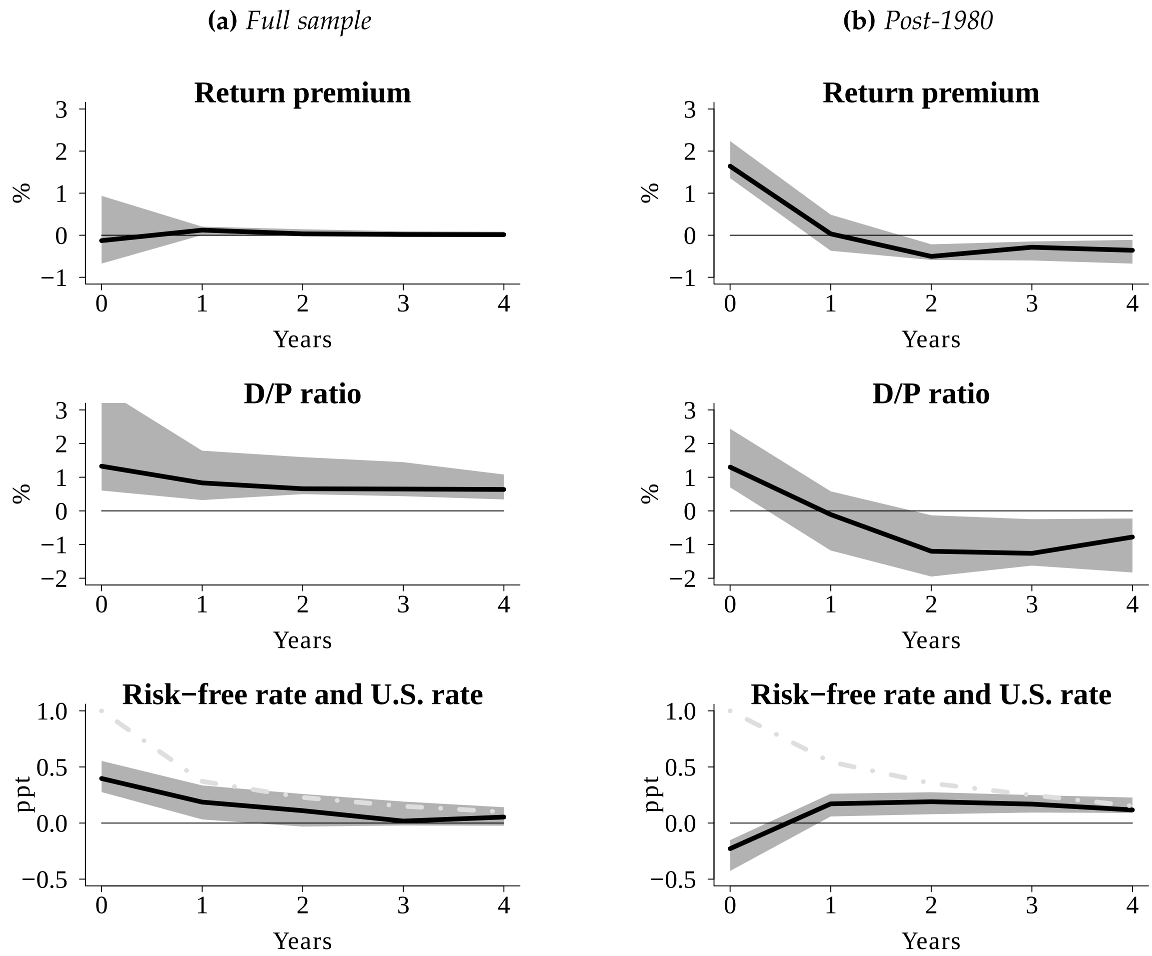
Overall, the VAR decomposition confirms our earlier result, that neither dividends, nor risk-free rates can explain the late 20th century surge in equity comovement. Instead it is risk appetite or, put in terms of the terminology used here, revisions to expected future return premiums, that are the primary explanation for the increasing comovement of equities.

International response to U.S. risk-free rate changes

By extending the VAR framework introduced above it becomes possible to trace the effects of U.S. monetary policy on return premiums, dividend-price ratios and risk-free rates, within a framework that acknowledges that ex post realized variables can deviate from their ex ante expected counterparts. This is achieved by incorporating U.S. interest rate policy innovations ΔR_t^{US} into the VAR system (see Bernanke and Kuttner, 2005):

$$\boldsymbol{z}_{t+1} = \boldsymbol{A}\boldsymbol{z}_t + \boldsymbol{\phi}\Delta\boldsymbol{R}_t^{US} + \boldsymbol{\epsilon}_{t+1}. \tag{3.A.15}$$

Figure 3.56: *Response to +1ppt U.S. policy rate increase*



Notes: Median bilateral impulse response functions to +1ppt increase in U.S. interest rates. Dashed gray – U.S. short-term real risk-free rate own response. 95% interval based on cross-sectional block-bootstrap procedure over bilateral country-pairs.

As our indicator for U.S. short-term rate innovations we use the residuals from a Taylor rule regression of U.S. real short-term rate changes on changes in U.S. real per capita GDP, U.S. CPI inflation and U.S. real stock prices, as well as one lag of each regressor. The responses of international equity return premiums, dividend-price ratios, and real short-term rates can then be calculated as $A^k\phi$.

Figure 3.56 displays the resulting impulse response functions for the full sample, as well as the post-1980 sample of high equity return premium co-movement. For the full sample dividends and risk-free rates react to U.S. monetary policy innovations, but not equity return premiums. In contrast, after 1980, equity return premiums exhibit a marked response. International risk-free rates respond less after 1980, than before, while the dividend-price ratio responds similarly in the full- and the post-1980 samples.

In sum, these findings support the evidence presented earlier, which suggests that the effect of U.S. monetary policy on international equity return premiums has gained strength in the past few decades.

3.A.4. *Explaining the reaction to U.S. risk-free rate changes*

We can also decompose the effect of U.S. rate innovations on equity return premiums in order to determine whether U.S. monetary policy affects international return premiums through revisions in expectations about future return premiums, dividends or risk-free rates. This can be achieved by multiplying equations 3.A.9 to 3.A.11 with ϕ, the vector describing the contemporaneous response of all variables in z to U.S. risk-free rate innovations. Accordingly, the response of the return premium news of country i is

$$\boldsymbol{g}_1^i \rho_i \boldsymbol{A}(\boldsymbol{I}-\rho_i \boldsymbol{A})^{-1} \boldsymbol{\phi}, \tag{3.A.16}$$

and the response of real risk-free interest rate news is

$$\boldsymbol{g}_2^i (\boldsymbol{I}-\rho_i \boldsymbol{A})^{-1} \boldsymbol{\phi}. \tag{3.A.17}$$

In accordance with equation 3.A.13 the response of the present value of expected future dividends is

$$\boldsymbol{g}_1^i \boldsymbol{\phi} + \boldsymbol{g}_1^i \rho_i \boldsymbol{A}(\boldsymbol{I}-\rho_i \boldsymbol{A})^{-1} \boldsymbol{\phi} + \boldsymbol{g}_2^i (\boldsymbol{I}-\rho_i \boldsymbol{A})^{-1} \boldsymbol{\phi}. \tag{3.A.18}$$

Table 3.7 displays the median response over all 16 country-pairs for the full sample, and the post-1980 sample. The post-1980 results indicate that revisions in the expectation about future return premiums explains most of the current return premium response. News about dividends and risk-free rates play smaller roles. In contrast, over the full sample revisions in the expectation about future dividends explains most of the current return premium response, while news about future returns and risk-free rates play a smaller role.

This confirms our earlier finding based on another methodology. The post-1980 increase in international equity comovement was driven by factors other than dividends and risk-free rates.

Table 3.7: *The impact of U.S. monetary policy on dividends, interest rates and future premiums*

	Full sample	Post-1980
Current return premium	**0.76**	**1.99**
-Future return premiums	**-0.54**	**1.97**
-Risk-free rate	**-0.48**	**-0.98**
Dividends	**1.78**	1.00

Notes: Bold type – 95% significance-level based on cross-sectionally block-bootstrapped confidence bands.

Chapter 4

When do fixed exchange rates work? Evidence from the Gold Standard

Joint with Yao Chen

4.1. Introduction

The pre-1914 Gold Standard was a global fixed exchange rate regime of colossal extent: By 1913 economies responsible for 67% of world GDP and 70% of world trade had relinquished flexible exchange rates as a means to unwind external imbalances. Yet external adjustments were associated with few, if any, output costs (see Meissner and Taylor, 2006; Adalet and Eichengreen, 2007). How did the Gold Standard (GS) equilibrate so smoothly despite inflexible exchange rates? There exist various competing, though not mutually exclusive explanations. First, prices were relatively flexible, allowing for a faster absorption of shocks (Backus and Kehoe, 1992; Basu and Taylor, 1999; Chernyshoff, Jacks and Taylor, 2009). Second, cyclical international migration helped to turn around the current account and took the pressure off of wages in depressed regions (e.g. Hatton, 1995; Khoudour-Castéras, 2005). Finally, central banks could smooth out temporary disturbances by running down their reserves (see Bazot, Bordo and Monnet, 2014; Eichengreen and Flandreau, 2014) or by making use of the considerable monetary policy independence that the Gold Standard, as a target zone regime, afforded in the short run (Krugman, 1991; Svensson, 1994; Bordo and MacDonald, 2005). The purpose of this paper is to provide a quantitative assessment of the relative importance of each of these channels. Can we determine which one reduced output volatility the most? Were they equally important – or were they most effective in combination?

In order to quantitatively assess the relative importance of flexible prices, international migration and monetary policy we built the first open-economy model of the Gold Standard that features international migration, various degrees of price flexibility and an elaborate monetary structure. We estimated the model with Bayesian methods and then studied the estimated model's behavior through counterfactual simulations: How would output volatility have looked had prices been less flexible? What if there had been no release through migration? How important was countercyclical monetary policy? The first main finding of this paper is that price flexibility was paramount for the benign adjustment experience under the Gold Standard. Neither restrictions on migration, nor the elimination of countercyclical monetary policy would have given rise to substantially higher output-volatility.

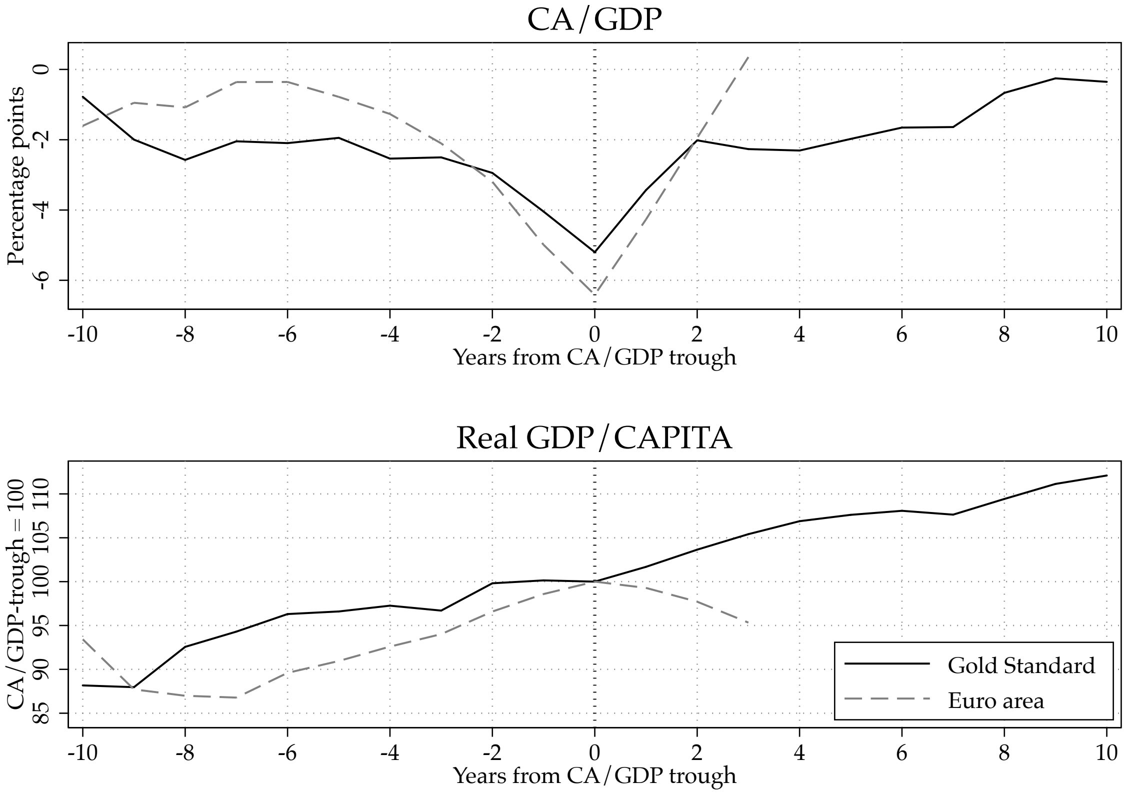
The second main finding of this paper is that price flexibility and benign external adjustment was predicated on production and trade concentrating in the primary sector: Agricultural products generally exhibit significantly more flexible prices than industrial or service goods. Prior to 1913 agricultural products still made up the majority of all merchandise exports, even among early industrializers. This fortunate coincidence of the nominally most flexible sector also being the most important tradable sector is the main explanation for the ease of external adjustment under the pre-1913 Gold Standard. On the basis of newly collected disaggregate export, price and production data we show that Gold Standard economies experienced a pronounced shift in sectoral structure in the face of a current account reversal. That is a shift, away from the production of non-tradables (primarily services) towards the production of tradable agricultural goods. This sectoral shift was brought about by quickly falling agricultural prices that directly translated into a boom in agricultural exports.

A study of external adjustment under the Gold Standard is particularly interesting in light of the often painful adjustment experiences in fixed exchange rate regimes today. Figure 4.1, for example, contrasts external adjustment under the Gold Standard with that in the euro area:[1] Under the Gold Standard as well as in the euro area the current account-to-GDP (CA/GDP) ratio on average decreased by about 5 percentage points in the 10 years prior to reversing sharply. However, while reversals were associated with major recessions in the euro area, under the Gold Standard output continued to grow on trend. The Gold Standard thus also provides an auspicious historical contrast to more recent external adjustments where exchange rates are fixed. Additionally, the pre-1913 Gold Standard lasted longer than most international fixed exchange rate regimes and thus provides a unique opportunity to analyze external adjustment under fixed exchange rates for an unaltered set of countries over more than three decades.

The paper is structured as follows: The following section introduces the data. After that, Section 4.3 gives an empirical outline of the behavior of prices, migration and monetary policy during major external adjustment episodes under the Gold Standard. Here we show that: (i) a strong price-decline in regions facing a current account-reversal quickly increased their price-competitiveness, (ii) migration flows redistributed labor supply from deficit regions to surplus regions, and (iii) central banks made use of the short-run independence they enjoyed under the Gold Standard. Sections 4.4 and 4.5 presents the Gold Standard-model and its estimation. The relative importance of prices, migration and monetary policy are then analyzed on the basis of counterfactual model simulations in Section 4.6. Section 4.7 substantiates our findings from the

[1] CA/GDP troughs are defined according to a turning-point algorithm (see Bry and Boschan, 1971). CA/GDP-troughs are defined as the lowest CA/GDP-value in a $\pm$10-year window. For the EZ a $\pm$8-year window was chosen and border conditions were weakened because of the shorter sample length.

Figure 4.1: *Average GDP- and CA/GDP-behavior around major CA/GDP-reversals*



Notes: The averages are based on a sample of 14 GS countries and 12 EZ countries respectively. Major adjustment periods are defined as the periods lasting from one CA/GDP trough to the next. CA/GDP troughs are defined according to a turning-point algorithm à la Bry and Boschan (1971): CA/GDP-troughs are defined as the lowest CA/Y-value in a ±10-year window. For the EZ a ±8-year window was chosen and border conditions were weakened because of the shorter sample length. GS: 9 CA/GDP troughs. EZ: 7 CA/GDP troughs.

model simulations with evidence from disaggregate price- and export data that suggests large primary sector shares and the dominance of primary products in international trade played a crucial role for external adjustment under the Gold Standard. Section 4.8 then concludes our analysis.

4.2. Data

The empirical foundation of our analysis is a new annual dataset for 14 countries that were members of the Gold Standard throughout the 1880-1913 period, namely Australia, Belgium, Canada, Denmark, Finland, France, Germany, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the U.K. and the U.S (`http://dx.doi.org/10.17632/wch3rbkxp7.2`). By focusing on a sample of 14 Gold Standard members whose commitment to gold was never seriously questioned in the period under consideration we exclude the topic of peg-credibility from our analysis. This allows us to squarely focus on the issue of external adjustment under inflexible exchange rates.

In many cases we were able to draw extensively from previous historical data collections by economic historians. In other cases new data had to be compiled from the historical publications of contemporary statistical offices, central banks and trade agencies. Particular effort went into the construction of a novel set of effective exchange rates, gold cover ratios and sectoral export- and price level data. The construction of these series is described in more detail in the following section.

All in all, our dataset covers the following annual time series: nominal GDP, real per capita GDP, consumer prices, the current account, imports and exports, the nominal exchange rate, immigration and emigration, population, discount rates, note circulation, nominal and real effective exchange rates, gold cover ratios, sectoral production shares, sectoral exports, sectoral price level data, terms of trade, and export prices. A detailed listing of all the sources is provided in Online Appendix 4.A.3. Further data descriptions, as well as reliability and validation checks for the sectoral data and migration series can be found in Appendices 4.A.3, 4.A.3 and 4.A.3.

4.2.1. *Effective exchange rates*

The real effective exchange rate of country i is calculated as the trade-weighted geometric average of bilateral real exchange rates ($RER_{i,j,t}$) with respect to countries $j \in 1, ..., J$

$$REER_{i,t} = \prod_{\substack{j=1 \\ j \neq i}}^{J} RER_{i,j,t}^{w_{i,j,t}},$$

where $w_{i,j,t}$ is the bilateral trade weight. The real exchange rate is the product of the nominal exchange rate[2] and the ratio of consumer prices, $RER_{i,j,t} = NER_{i,j,t} \frac{CPI_{i,t}}{CPI_{j,t}}$.[3] Our baseline $REER$ estimate uses the bilateral trade flow data provided by López-Córdova and Meissner (2008) and Mitchell (2013) as trade weights.[4] Trade weights $w_{i,j,t}$ equal the ratio of total bilateral trade to GDP, $(imports_{i,j,t} + exports_{i,j,t})/GDP_{i,t}$. In accordance with modern-day REER estimates, as provided for example by the ECB, we updated the bilateral trade-weights every three years. Note that we exclusively consider GS-member economies for the REER calculation. We do this in order to focus on competitiveness within the GS.[5] Along the same lines we constructed

[2] Here the nominal exchange rate is written in quantity notation, i.e. foreign currency per domestic currency.

[3] This method of data aggregation into a foreign composite flows from a setup in which preferences are characterized by a unit-elasticity of substitution between foreign goods varieties. Another advantage of using the weighted geometric average is that the REER that is calculated on the basis of exchange rates quoted in price-notation is exactly the inverese of the REER calculated on the basis of exchange rates quoted in quantity notation.

[4] We linearly intrapolate the trade-weights and use the first and last observation of each country-pair to fill in missing values at the beginning and end of the sample.

[5] This differentiates our REER series from those introduced by Catão and Solomou (2005), whose REER series are affected by fluctuations in the nominal exchange rate with respect to non-Gold Standard

nominal effective exchange rates (NEER) and foreign effective consumer price indices as trade-weighted geometric averages. The final REER series are displayed in Figure 4.8 in Online Appendix 4.A.3.

4.2.2. Gold cover ratios

Another crucial variable for our attempt to characterize external adjustment under the GS are gold cover ratios. In its simplest form a legally defined gold cover ratio required the central bank to back a certain fraction of its note issue with gold. In more general terms, cover ratios required central banks to back their liquid liabilities with liquid assets. The exact legal definition of cover ratios however differed across countries and time.[6] In order to capture this definitional ambiguity we decided to construct two different measures of the gold cover ratio – one narrow and one broad. The narrow cover ratio is the ratio of metal reserves (gold and silver) to notes in circulation. The broad cover ratio adds foreign exchange reserves to the numerator and central bank deposits to the denominator. This allowed us to select the cover ratio that comes closest to the legally defined one for each country. For example since 1877 the numerator of the cover ratio targeted by the National Bank of Belgium included foreign exchange reserves. Thus in our model estimation for Belgium we used the broad cover ratio series. The narrow and broad cover ratio series are displayed in Figures 4.9 and 4.10 in Online Appendix 4.A.3.

4.2.3. Sectoral shares, prices and exports

In order to see which sector drove external adjustment during the GS we collected disaggregated price- and export data, as well as primary sector shares. The export data are disaggregated into agricultural-, raw material- and industrial exports. The sectoral price data features the same three categories as well as service prices. While some sources provide data at this level of aggregation, in many cases we had to aggregate up from more readily available product-level data. The sectoral data are described in more detail in Online Appendices 4.A.3 and 4.A.3. The sectoral value-added share data come from Buera and Kaboski (2012).

4.3. Stylized facts

In order to get a first impression of how prices, migration and monetary policy behaved during major external adjustments under the Gold Standard (GS) this section introduces a set of stylized facts. To this end we identify troughs in the current account to GDP ratio (CA/GDP)

members. For our 14 country sample of long-term Gold Standard adherents an average of 75% of imports came from other countries in the sample and an average of 84% of exports went to other countries in the sample. Although there is some variation across countries and time in these within-GS trade shares, even the minimum intra-GS import share of 53% and the minimum intra-GS export share of 66% are sizeable.

[6]Bloomfield (1959) provides a summary of the main types of legal cover ratios.

through a Bry and Boschan (1971)-style algorithm: CA/GDP-troughs are defined as the lowest CA/GDP-value in a ±10-year window. For the period between 1880-1913 we thus identify 9 CA/GDP troughs (see Figure 4.14 in Online Appendix 4.A.3).[7]

We then look at how the average behavior of prices, migration and monetary policy ($x_{i,t}$) after such major CA/GDP-reversals differs from their average behavior after non-reversal years. More formally we look at the sequence of differences

$$D_h(x_{i,t+h}, A_{i,t}) = E_{i,t}(x_{i,t+h}|A_{i,t} = 1) - E_{i,t}(x_{i,t+h}|A_{i,t} = 0), \quad h = 1, ..., H \tag{4.1}$$

where $A_{i,t}$ equals 1 if the economy i enters a major adjustment phase at time t, and 0 otherwise. h indicates the temporal distance from the start of the adjustment phase. Thus $D_h(x_{i,t+h}, A_{i,t}), \quad h = 1, ..., H$ stands for the different behavior of x_i after major CA/GDP-reversals relative to non-reversals.

Practically, we estimate the sequence of differences $D_h(x_{i,t+h}, A_{i,t})$ through the following sequence of fixed effects models:

$$\frac{x_{i,t+h} - x_{i,t}}{x_{i,t}} = \alpha_{i,h} + \beta_h A_{i,t} + u_{i,t+h}, \quad h = 1, ..., H \tag{4.2}$$

where α_i are country-fixed effects and $u_{i,t}$ is an error term. The $\{\beta_h\}_{h=1,...,H}$ in expression 4.2 allow us to sketch out the average behavior of macroeconomic aggregates over the H years following a major CA/GDP-trough. This will provide us with a set of stylized facts on how GS-member economies typically behaved during major adjustment phases in contrast to their behavior during "normal" times.[8]

The first row of Figure 4.2 shows that the typical adjustment during the GS featured a sharp increase in exports that led to a quick turn-around in the current account. Lower import levels also temporarily contribute to the reversal. In general, however, external adjustments under the GS were export-driven. How did prices, migration and monetary policy behave during these episodes? The second row in Figure 4.2 shows that domestic prices fell strongly and swiftly during adjustment phases. The brunt of the adjustment is furthermore born by domestic prices, with foreign prices remaining stable. As a consequence, the fall in domestic prices translates almost one-to-one to a gain in relative price competitiveness of around 6%.

How about migration? The third row of Figure 4.2 shows that about 5 years into the adjustment, the average GS economy's population was about 0.5% smaller due to the reduction in immigration and an increase in emigration.[9] This indicates that in the typical external

[7] As a robustness check we have also considered an alternative set of CA/GDP-troughs. In particular we extended the selection to include any visually salient trough in the CA/GDP-ratio that was followed by a prolonged period of increasing CA/GDP-ratios. Results are generally robust to this alternative selection (see Online Appendix 4.A.3).

[8] This approach is more familiar as the local projection framework for estimating impulse response functions (Jorda, 2005) . Here however the $\{\beta_h\}_{h=1,...,H}$ are used for the depiction of historical averages and should not be interpreted as impulse response functions.

[9] Note that due to sample difference arising from the fact that there are several countries for which

adjustment under the GS migration played only a minor, albeit systematic role. However, for some economies migration flows could be more sizeable. Consider the case of Sweden in the 1880s, which for the best part of the decade lost close to 1% of its population per year. Assuming that at the end of such a decade the population level is only 5% lower than what it would have been without migration, a back-of-the-envelope calculation places the direct CA/GDP effect, stemming from emigrants lowering origin-country imports, in the +1 to +2 ppt range.[10] This constitutes a considerable contribution to external adjustment.

The same 5% population decline furthermore increases origin-country wages, and thus stabilizes incomes. For a Cobb-Douglas production function, that is parametrized to a labor share of income of around 66%, a 5% decrease in the labor supply thus implies a non-negligible wage increase in the range of 1-2%.[11] Thus for Sweden, migration might have been more central to external adjustment than for other countries at the time.

Note, however, that the effect of migration on output is not unambiguously stabilizing. Destabilizing effects arise in the short-run when recessionary origin economies lose internal demand to already expanding host economies (see Farhi and Werning, 2014). When this channel is taken into account migration is less likely to have a stabilizing influence, because it now exerts opposing forces that can cancel each other out.[12]

Turning to the monetary side of external adjustment under the Gold Standard, the last row in Figure 4.2 displays the behavior of the central bank discount rate, gold cover ratio and the nominal effective exchange rate. In general, monetary policy turned accommodative during major external adjustments. Central bankers used their freedom to conduct independent discount rate policy within the target zone and, on average, lowered discount rates by 100 basis points. Some central banks made more extensive use of their freedom than others. To get an idea of how much discount rate independence a $\pm 1\%$ target zone regime allowed for, consider that a 1% depreciation of the exchange rate - that is expected to disappear within one quarter - allows a central bank to temporarily set its policy rate 4 ppts below world levels.[13] This can explain how in some years the discount rates set by several Scandinavian central

only immigration or emigration exists, but not both, the Immigration/Population and the Emigration/Population graphs do not necessarily add up to the Net Immigration/Population graph.

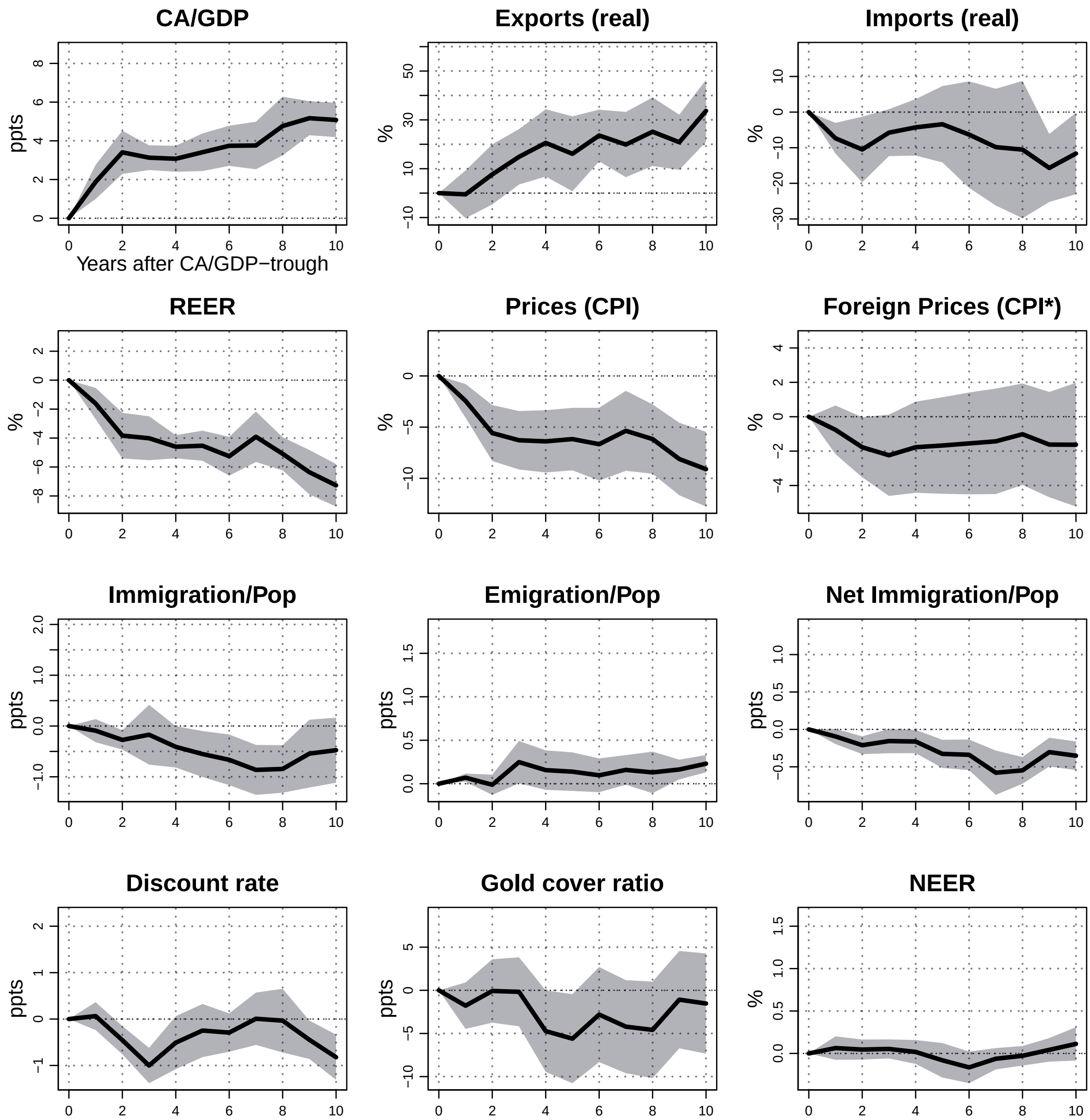
[10] This assumes that Swedish households consume around 75% Swedish-produced goods and 25% foreign-produced goods, which corresponds to Sweden's actual average import to GDP ratio for the period 1880 to 1913. Also note that the assumed 5% population decline can be considered conservative.

[11] Note that such wage effects will slightly dampen the direct CA/GDP effect of migration.

[12] In the model, migration's net effect on output stability will thus hinge upon the interaction of various parameters, such as home bias in consumption, the curvature of the production function with respect to labor input as well as all of the rigidities that influence the two regions' response to short-run changes in aggregate demand.

[13] This example is taken from Bordo and MacDonald (2005). Note that, to the extent that the central bank's countercyclical policy rule is known and expected by agents, this influences ex ante inflation expectations and thus real rates even before the central bank has taken any action. Thus observed differences in nominal rates are imperfect indicators of the effectiveness of monetary policy independence during the GS.

Figure 4.2: *Prices, migration and monetary policy after major reversals in the CA/GDP-ratio*



Notes: Black solid – Gold Standard. Shaded areas – 90% confidence bands based on robust Driscoll-Kraay standard errors (small sample corrected, autocorrelation lag order = 2 years). CA/GDP-troughs are defined according to a turning-point algorithm à la Bry and Boschan (1971): CA/GDP-troughs are defined as the lowest CA/GDP-value in a ±10-year window. The number of CA/GDP-troughs thus identified is nine.

banks deviated by up to 3 percentage points from those set by the Bank of England.[14] In the short-run the GS left central bankers with considerable flexibility for setting their discount rates with a "concern for home trade" (Sayers (1976) vol I, p.44, Bordo and MacDonald (2005)).

[14]Due to the absence of large inflation differentials this translated into almost identical real rate differentials.

Beyond the limited monetary policy independence they enjoyed within the target zone, central bankers were furthermore willing to round the corners of the policy trilemma through active intervention in foreign exchange markets or through the passive accommodation of gold outflows. Figure 4.2 shows that during major external adjustments such policies resulted in a 5 ppt drop in gold cover ratios. The National Bank of Belgium and the Banque de France were particularly willing to let their gold cover ratios fluctuate in order to insulate the domestic economy from movements in world interest rates (Eichengreen and Flandreau, 2014; Bazot, Bordo and Monnet, 2014). Thus, the pre-1913 GS was in possession of several safety valves on the monetary side that could ease external adjustment.[15]

To sum up, a typical external adjustment under the GS was accompanied by a strong and swift gain in price-competitiveness. Migration- and monetary policy also reacted. For individual countries activity along the latter two channels could become pronounced enough to exert a non-negligible stabilizing force on per capita incomes– e.g. Sweden in the case of migration, and Belgium in the case of monetary policy. Against the backdrop of these empirical regularities we now introduce a structural model in order to quantitatively assess the relative importance of price flexibility, migration and monetary policy in explaining the stability of incomes during external adjustments under the GS.

4.4. A model of the Gold Standard

To quantitatively analyze the relative importance of prices, migration and monetary policy for the ease of external adjustment under the Gold Standard we need to be able to disentangle their individual impact. To this end, we introduce a two-region open economy model that features international migration flows, various degrees of price flexibility and a GS-specific monetary structure.[16]

In the following section, we will first shortly outline the model and thereby focus mainly on decision problems in one of the two regions – the *H*-region. The economy in the *F*-region is symmetric and we provide a more detailed description of the complete equation system that characterizes its state of equilibrium in Appendix 4.A.1.

4.4.1. Households

There is a continuum of households $i \in [0, 1]$, with households $[0, n_t)$ living in H and $[n_t, 1]$ in F. Household i's period utility follows the Greenwood, Hercowitz and Huffman (1988) (GHH)

[15]The outlined relationship of prices, migration, and monetary policy with movements in the CA/GDP ratio is a robust characteristic of the GS data. It also shows up in within year correlations (see Table 4.14 in Online Appendix 4.A.4), as well as an alternative definition of CA/GDP troughs (see Figure 4.15 in Online Appendix 4.A.3).

[16]The 2-region model abstracts from those countries that were not part of the Gold Standard. As a robustness check we therefore also estimated a version of the model in which we treat one of the regions as a hybrid that includes all other gold, as well as non-gold countries. The presented results are robust to this alteration (see Online Appendix 4.A.3).

form. The household maximizes its life time utility[17]

$$V_t^i = \mathbb{E}_t \sum_{k \geq 0}^{\infty} \beta^k \frac{1}{1-\sigma_c} \left(c_{t+k}^i - \frac{1}{1+\sigma_l} {l_{t+k}^i}^{1+\sigma_l} \right)^{1-\sigma_c},$$

where β is the discount factor, l_t is hours worked and c_t is consumption, which is made up of H- and F-produced goods: $c_t = \left[(1-\alpha)^{\frac{1}{\epsilon}} c_{H,t}^{\frac{\epsilon-1}{\epsilon}} + \alpha^{\frac{1}{\epsilon}} c_{F,t}^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}$. The elasticity of substitution between these goods is ϵ and the openness parameter α reflects a home-bias in taste as well as trade frictions. The H and F goods themselves are CES bundles of differentiated goods that are produced by the n home- and $1-n$ foreign firms: $c_{H,t} = \left(\left(\frac{1}{n}\right)^{\frac{1}{\mu}} \int_0^n c_{H,t}(j)^{\frac{\mu-1}{\mu}} \, \mathrm{d}\, j \right)^{\frac{\mu}{\mu-1}}$ and $c_{F,t} = \left(\left(\frac{1}{1-n}\right)^{\frac{1}{\mu}} \int_n^1 c_{F,t}(j)^{\frac{\mu-1}{\mu}} \, \mathrm{d}\, j \right)^{\frac{\mu}{\mu-1}}$, where j is the firm index and μ is the elasticity of substitution between goods produced in the same region. The price indices for the H- and F-produced goods bundles are $P_{H,t} = \left[\frac{1}{n} \int_0^n P_{H,t}(j)^{1-\mu} \, \mathrm{d}\, j \right]^{\frac{1}{1-\mu}}$ and $P_{F,t} = \left[\frac{1}{1-n} \int_n^1 P_{F,t}(j)^{1-\mu} \, \mathrm{d}\, j \right]^{\frac{1}{1-\mu}}$. The H consumer price index is then given by $P_t = \left[(1-\alpha) P_{H,t}^{1-\epsilon} + \alpha P_{F,t}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}$. We assume that the law of one price applies at the individual goods level so that $P_{F,t}(j)\, e_t = P_{F,t}^*(j)$, where F-variables are marked by an asterisk and e_t denotes the nominal exchange rate (domestic per foreign currency).[18] Note, however, that due to the existence of home bias in consumption LOP does not imply purchasing power parity (PPP).[19]

The households' budget constraint is

$$\begin{aligned} & B_{H,t-1}^i R_{t-1}^e + B_{F,t-1}^i R_{t-1}^{e*} / e_t + TR_t + P_t w_t \, l_t^i + \Gamma_t + I_t^\tau \\ & = B_{H,t}^i + B_{F,t}^i / e_t + P_t \, c_t^i + P_t \, \frac{K}{2} \left(\frac{{B^i}_{F,t}}{P_t e_t} - \bar{o} \right)^2 \end{aligned}$$

where F-variables are marked by an asterisk. $P_t w_t$ is the nominal wage households receive for supplying their labor to local firms on competitive labor markets. Γ_t are local firms' nominal lump-sum dividends that are payed out to local households. $B_{H,t}^i$ and $B_{F,t}^i$ are household i's holdings of two internationally traded one-period risk-free bonds, denominated in H- and F currency respectively. R_t^e is the effective return, which is determined by the risk-free rate R_t and a risk premium shock ϵ_t^b as $R_t^e = R_t / \exp(\epsilon_t^b)$. The adjustment of foreign real asset

[17] Schmitt-Grohé and Uribe (2003), Mendoza (1991) and Mendoza and Yue (2012) point out that open economy models with GHH utility functions are better at replicating business cycle statistics than models with utility functions where labor supply is subject to wealth effects.

[18] While the law of one price (LOP) assumption is an exaggeration (see Persson, 2004), price differentials were generally declining over the 19th century, so that by the end of the century they had become a fraction of what they used to be at its beginning (see Klovland, 2005; Jacks, 2005).

[19] See Diebold, Husted and Rush (1991) and Taylor (2002) for analyses of purchasing power parity (PPP) in the 19th and 20th centuries. While PPP held in the long-run, there could be considerable deviations from PPP over short and medium horizons.

holdings is subject to a quadratic adjustment cost, which is the last term of the budget constraint equation.[20] When households in F adjust their portfolio holding of H bonds, the associated cost is transferred to H households in a lump-sum fashion: $TR_t = \frac{n_t^*}{n_t}\frac{P_t^*}{e_t}\frac{K^*}{2}\left(\frac{B^i{}_{H,t}e_t}{P_t^*} - \bar{o}^*\right)^2$. Portfolio adjustment costs and risk premium shocks allow for deviations from strict uncovered interest parity (UIP). Because of migrations, the model has four different household types - denoted by τ: H- and F-households that either stay or migrate $\tau \in \{H \to H, H \to F, F \to H, F \to F\}$, where $\to$ shows the direction of migration. The type-specific and possibly negative payment I_t^τ ensures that nominal asset holdings after migration are equalized across households within the region.

4.4.1.1 Endogenous migration

In our model households are free to migrate back and forth between the H and F regions.[21] At the beginning of each period, exogenous shocks realize and households choose whether to migrate ($\delta_t^i = 1$) or to stay ($\delta_t^i = 0$). The decision to migrate is based on comparing the lifetime utilities of continuing to live in H (V_t^i) to that of moving to F. The utility of moving to F includes the utility of living there (V_t^{i*}) minus the costs of moving. There exist two short-term costs of moving: One is a time-invariant, region specific migration cost κ_d, which reflects the various hindrances migrants have to overcome (e.g. travel costs). The other is a stochastic utility shock v_t^i that captures the cross-population idiosyncrasy and cross-time variation in a household's preference for leaving its current location.[22] The household i's migration decision is

$$\delta_t^i = \arg\max_{\delta_t^i \in \{0,1\}} \{V_t^i, \quad V_t^{i*} - v_t^i - \kappa_d\}.$$

We assume that the *i.i.d.* utility shock v_t^i follows a logistic distribution with a mean of zero and scale parameter ψ. An individual household's migration probability is

$$d_t^i = Prob\left(V_t^{i*} - \kappa_d > V_t^i\right).$$

After migrations have taken place, the type-specific transfers I_t^τ ensure that nominal asset holdings at the beginning of the period are the same across households within a region. They thus can be treated as identical and we drop the household index i.[23] As a consequence the

[20] We assume the same functional form as Benigno (2009). The adjustment cost also pins down the steady state gross foreign asset position. The model's steady state for net foreign assets is determined even without the adjustment costs due to migration (see Appendix 4.A.1).

[21] Kennan and Walker (2011) also develop an econometric and dynamic model of migration that features optimal location decisions over many alternative locations. They model individual decisions to migrate as a job search problem and focus on the partial equilibrium response of labor supply to wage differentials.

[22] This ensures that not all households migrate at the same time.

[23] Type changing, or in our case migration, causes difficulties in tracking a household's asset position. Cúrdia and Woodford (2010) construct an insurance scheme for households that change types with an exogenous probability. The insurance equalizes the marginal utility of income for households of the

population fraction that emigrates, $\widetilde{d}_t$, equals the emigration probability, d_t.[24] The aggregate population in H, therefore, evolves according to[25]

$$n_t = (1 - \widetilde{d}_t)\, n_{t-1} + \widetilde{d}^*_t\, n^*_{t-1}. \tag{4.3}$$

4.4.2. Firms

The model's production side consists of a continuum of monopolistic competitive firms $j \in [0, 1]$ that maximize expected discounted profits. The n home firms and $1 - n$ foreign firms produce with labor from H and F households respectively. The production technology is $y_t(j) = \exp(A_t) L_t(j)^\gamma$, where $y_t(j)$ is output, $L_t(j)$ is labor and A_t is the exogenous region-specific productivity level. γ parameterizes the curvature of the production function with respect to labor and thus determines the de- and reflationary effects of migration on wages in receiving and sending regions. As in Calvo (1983), firms face a nominal rigidity, where in each period only a random fraction $(1 - \theta)$ of firms can reset their prices.[26] θ, together with γ and μ determine the slope of the Phillips curve according to $\widetilde{\kappa} = \frac{(1-\beta\theta)(1-\theta)}{\theta(1-\mu+\mu/\gamma)}$.[27]

4.4.3. Equilibrium

In equilibrium the following market clearing conditions for financial-, goods- and labor markets hold:

$$\begin{aligned}
0 &= n_t B_{H,t} + n^*_t B^*_{H,t} \\
0 &= n_t B_{F,t} + n^*_t B^*_{F,t} \\
y_t(j) &= n_t\, c_{H,t}(j) + n^*_t\, c^*_{H,t}(j), \quad j \in [0, n) \\
y^*_t(j) &= n_t\, c_{F,t}(j) + n^*_t\, c^*_{F,t}(j), \quad j \in [n, 1] \\
n_t\, l_t &= \int_0^n L_t(j)\, dj, \quad j \in [0, n) \\
n^*_t\, l^*_t &= \int_n^1 L^*_t(j)\, dj, \quad j \in [n, 1]
\end{aligned}$$

same type. In our model, such an insurance scheme is, however, infeasible, due to the endogeneity of the migration decision. Here, we resort to the pooling assumption in order to keep the model tractable. A similar pooling assumption has been used in Corsetti et al. (2013, 2014).

[24] While migration often lags behind business cycle conditions, Jerome (1926, p.241) states that the "most common lag in migration fluctuations is from one to five months". Migration thus does not feature any intrinsic persistence in our annual model.

[25] Note that population levels in the model are stationary, although deviations from the steady state can be very persistent.

[26] In accordance with the GS results reported by Benati et al. (2008) our model does not feature price (backward-) indexation.

[27] See Beckworth (2007) for evidence that nominal rigidities in late 19th century-economies were important enough to affect real economic activity.

4.4.4. Monetary policy and gold flows

Different strands of the literature have characterized monetary policy under the classical GS as either a money-quantity rule or a discount rate rule. According to the money-quantity view central banks were supposed to expand and contract the money supply in proportion to gold in- and outflows, such as to keep the ratio of gold-to-money - the gold cover ratio - stable. Another part of the literature, however, focuses on the importance of central bank discount rates in stabilizing the exchange rate. Here we model monetary policy as a discount rate rule that targets the gold cover ratio γ_t. This formulation integrates the money quantity view and the discount rate view in that discount rate policy R_t contributes to a stable money-to-gold ratio in the long-run. At the same time in the short-run, within the target zone, the central bank is free to let the gold cover ratio fluctuate in order to stabilize the domestic output gap.

In contrast to strict money-quantity rules, this depiction of monetary policy under the GS is in line with the observed fluctuation in gold cover ratios (see Online Appendix 4.A.3). Finally, we also allow central banks to directly target the nominal exchange rate e_t in order to accommodate the heterogeneity of discount rate policies that could be observed under the GS.[28] The discount rate rule is

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho} \left(\frac{y_t}{\bar{y}}\right)^{(1-\rho)\Phi_y} \left(\frac{\gamma_t}{\bar{\gamma}}\right)^{(1-\rho)\Phi_\gamma} \left(\frac{e_t}{\bar{e}}\right)^{-(1-\rho)\Phi_e} \exp(\epsilon_t^r),$$

where we allow for persistence in the discount rate, and Φ_y, Φ_γ and Φ_e denote the sensitivity of the discount rate reaction with respect to the output gap, the gold cover ratio and the exchange rate.[29]

Adherence to this discount rate rule implies deviations from a strict money-quantity rule. Money M_t varies with money demand according to a money demand function as in much of the earlier GS literature.[30] Money demand is assumed to be a fraction of the nominal value of

[28] For instance, Morys (2013) presents evidence that the core economies' discount rate policies were directly targeted at keeping the nominal exchange rate within the gold points, while in the periphery central banks put more weight on their gold cover ratios.

[29] Here the output gap is defined as the deviation of real output y_t from its steady state $\bar{y}$. We prefer defining the output gap in terms of deviations of real aggregate output from its steady state over definitions based on deviation from the *efficient* level of output or *per capita* output levels, because we consider the former to cohere more with contemporary central banks' targets and information sets. While the use of retrospectively constructed GDP series harbors an element of anachronicity we consider them to be a reasonable proxy for the more general business climate that central banks were reactive to.

[30] Here, we consider M_t to be narrowly defined as central bank notes in circulation. The holding of notes does not appear in the budget constraint. This is the case because we implicitly assume a cash-in-advanced constraint for central bank notes where asset markets are opened before goods trading. Households will convert all notes into bond holdings at the end of the period, because note-holding means the foregoing of interest revenues.

total production $n\, P_{H,t}\, y_t$ and depends on the discount rate R_t:

$$P_{H,t}\; n\, y_t = \exp(\chi_t)\, M_t\, k(R_t), \qquad k(R_t) > 0, \qquad v^r \coloneqq \frac{\partial k}{\partial R_t} \geq 0,$$

where χ_t is an exogenous money demand shock. Central bank gold stocks evolve according to

$$\begin{aligned} G_t &= G_{t-1} + F(e_t)\exp(\epsilon_t^m), \\ F(\bar{e}) &= 0, \quad \epsilon^e \coloneqq \frac{\partial F}{\partial e_t} \geq 0 \end{aligned} \tag{4.4}$$

where gold moves between H and F according to deviations of the nominal exchange rate from the ratio of the two currencies' underlying gold parities – i.e. their mint ratio (Officer, 1985; Giovannini, 1993; Canjels, Prakash-Canjels and Taylor, 2004; Coleman, 2007). When H and F central banks commit to convert local currency into gold at a fixed parity, deviations of the nominal exchange rate from the mint parity makes shipping gold between regions profitable. ϵ_t^m indicates an exogenous gold shock.[31] Given money M_t and gold G_t the gold cover ratio γ_t is determined by the relation

$$M_t = \frac{1}{\gamma_t} P_g G_t,$$

where P_g is the legal gold parity.

Finally, note that in this setup the long-run credibility and sustainability of the peg is never doubted. This allows us to focus on external adjustment when exchange rates are inflexible.

4.5. Bayesian Estimation

We loglinearize the model around its non-stochastic steady state (see Appendix 4.A.1) and estimate it with Bayesian techniques for the U.K., Sweden and Belgium.[32] For each estimation, we chose the country in focus – the U.K., Sweden or Belgium – to be the H region, while all other GS members were aggregated into the F region.

We selected Sweden and Belgium with an eye on obtaining upper bound estimates for the effectiveness of the migration- and monetary policy-channels respectively. In the late 19th century, Sweden was one of the countries with the highest emigration rate, losing between 0.3% and 1.1% of its population per year through emigration. Previous research has already pointed out that Swedish net immigration followed a pronounced countercyclical pattern that

[31] We also considered a version of the model in which gold flows are influenced by net immigration and the trade balance. However, our estimations showed neither of them to be an important determinant of gold flows. Gold coins carried by migrants constituted only a minute fraction of total gold flows, and in contrast to the 18th century price-specie flow model (Hume, 1752) by the late 19th century trade deficits and surpluses were no longer primarily settled through gold flows.

[32] The large number of parameters and the relative shortness of macroeconomic time series usually renders maximum likelihood estimation of medium-scale DSGE models infeasible.

might have aided external adjustment (see Khoudour-Castéras, 2005): Whenever the domestic economy went badly a sizeable fraction of the Swedish population headed for the New World, particularly the U.S.[33] For these reasons we expect Sweden to give us an upper bound estimate of how effective cyclical migration could be in easing external adjustment under the GS.

We select Belgium, because the National Bank of Belgium was renown for its willingness to let its gold cover ratio fluctuate in order to insulate the domestic economy from movements in world interest rates (Ugolini, 2012; Eichengreen and Flandreau, 2014). In fact, by the late 19th century Belgium was considered the prime example in this regard, due to the scale and scope of its foreign exchange market interventions (see Conant, 1910). The success of its policies in achieving a non-negligible degree of monetary autonomy within the GS did not escape international notice and even led to calls for emulation (see Palgrave, 1903; Schiltz, 2006). We thus expect that Belgium provides us with an upper bound estimate for the effectiveness of the monetary policy channel under the GS.[34]

Finally, we also estimate the model for the U.K. The U.K. was one of the earliest countries to abandon silver and switch to a purely gold-based monetary system already in the 18th century. As the first industrializer and subsequently the world's pre-eminent free-trader it motivated many trading partners to follow suit. The U.K. was in many ways the centerpiece of the Gold Standard (GS) – home to the world's largest financial center and hosting the most influential central bank of its time.

4.5.1. Observables

We estimate each model on the basis of 11 observables: domestic and foreign time series of per capita GDP; central bank discount rates and CPI-inflation; domestic time series for the ratio of net immigration to population[35]; the trade balance to GDP ratio; changes in the central bank notes in circulation; the gold cover ratio and the nominal effective exchange rate (NEER). The foreign time series are constructed as trade-weighted geometric averages, analogously to the previously discussed REER series (see Section 4.3). The ratio of net immigration to population and the trade balance to GDP ratio are directly detrended by a one-sided HP-filter ($\lambda = 100$). All other variables are first logged before being detrended by the same one-sided HP-filter.

[33] At that time, only Norway had a comparably high emigration rate with a similarly countercyclical pattern. Counterfactual simulation results for Norway are reported in Online Appendix 4.A.3. The results are in line with the conclusions drawn on the basis of the other three countries' estimation results.

[34] The Banque de France is another central bank that pioneered an activist approach to reserve and portfolio management. Counterfactual simulation results for France are reported in Online Appendix 4.A.3. These results lead to conclusions very similar to those we draw from the Belgian case.

[35] Most migration flows within our sample originate and end in one of the sample countries. Little of the large-scale migration to South America originated from within our sample. Instead it originated from non-persistent Gold Standard member countries, such as Italy, Spain and Portugal, that are also outside of our sample.

4.5.2. Calibration

Table 4.1: *Calibrated parameters*

Description		Value/Target
β	Discount factor	0.962
$\frac{\mu}{\mu-1}$	Markup	1.1
γ^*	Production function *F*	0.792
α	Openness parameter *H*	SST H import-to-GDP ratio
α^*	Openness parameter *F*	SST H export-to-GDP ratio
United Kingdom		
γ	Production function *H*	0.726
n	SST population *H*	0.160
$\bar{d}$	SST emigration *H*	0.0064
$\bar{o}$	Foreign portfolio *H*	SST H GFA-to-GDP ratio = 1.33
Sweden		
γ	Production function *H*	0.792
n	SST population *H*	0.020
$\bar{d}$	SST emigration *H*	0.0059
$\bar{o}^*$	Foreign portfolio *F*	SST F GFA-to-GDP ratio = 0.001
Belgium		
γ	Production function *H*	0.792
n	SST population *H*	0.027
$\bar{d}$	SST emigration *H*	0.0036
$\bar{o}^*$	Foreign portfolio *F*	SST F GFA-to-GDP ratio = 0.001

Notes: GFA gross foreign assets. SST steady state.

Some parameters are calibrated, either because they are difficult to estimate (e.g. markups) or because their identification from observables is straightforward (e.g. discount factors) (see Table 4.1). We follow standard calibration strategies for the time discount factor β, the within-country intra-temporal elasticity of substitution μ, the curvature of the production function γ, the trade-openness parameters α and α^*, and the steady state gross foreign asset position $\bar{o}$. The time discount factor β is set to 0.9615, in order to match a sample average discount rate of 4%. The elasticity of substitution between the goods within a country μ is set to 11, implying a steady state price markup of 10%.[36] Given μ, we calibrate γ to target a steady state *labor income* to *GDP* ratio of 0.66 for the U.K. and 0.72 for all other countries (Sweden, Belgium and the *F*-regions).[37] The first value reflects the average labor share in the U.K. from 1880-1913 and the later is an approximation based on the average labor share in France and Germany during the same time period.[38] The trade openness parameters α and α^* are calibrated to target the historical average *import* to *GDP*-ratios (U.K.: 30%, Sweden:

[36]This value is consistent with Jacks, Meissner and Novy (2010), who use an elasticity of substitution parameter of 11. A value of 11 implies a markup of 10% which nicely corresponds to the late 19th century markup estimate of 9.8% by Irwin (2003).

[37]The model's steady state labor income share is $\gamma(\mu-1)/\mu$

[38]According to the datasets provided by Hills, Thomas and Dimsdale (2015) and Piketty and Zucman (2014).

25%, Belgium: 47%) and *export* to *GDP* ratios (U.K.: 29%, Sweden: 24%, Belgium: 37%) of the H region. The U.K.'s gross foreign asset holdings $\bar{o}$ are set to target a steady state *gross foreign asset* to *GDP* ratio of 1.33, which is consistent with the gross foreign asset estimates provided by Piketty and Zucman (2014) and Obstfeld and Taylor (2004).[39] Calibrating steady state gross foreign asset (GFA) positions for Sweden and Belgium is less straightforward due to the lack of historical data. We assume that in the steady state the F-region holds few Swedish or Belgian assets relative to its GDP, $GFA/GDP = 0.001$. Together with the steady state net foreign asset position, this pins down the steady state gross foreign asset holdings of Sweden and Belgium.[40]

The introduction of migration to the model necessitates the calibration of steady state values for population levels n and emigration rates $\bar{d}$. Fortunately this is relatively straightforward: The steady state population level of H is chosen to correspond to the average *domestic population* to *sample population* ratio. The steady state emigration probability in H ($\bar{d}$) is set to the average *emigration* to *population* ratio of the H country (U.K., Sweden or Belgium). This implies the corresponding steady state value for F according to the equality $\bar{d}\,n = \bar{d}^*\,n^*$.

4.5.3. *Prior distribution*

The prior distribution is selected according to the *endogenous prior* method introduced by Christiano, Trabandt and Walentin (2011), who use observables' moments to adjust an initial prior choice. The endogenous prior approach is particularly attractive for our analysis because prior information on the model parameters for the GS era is relatively scarce. In particular, we use the second moments of the observables to form the endogenous prior. This helps to improve the model's fit of the observables' variances.[41]

The prior distributions for the estimated parameters are summarized in Table 4.2. We assume that the inverse elasticity of intertemporal substitution σ_c and the inverse Frisch elasticity σ_l are identical across regions. Their prior distribution follows the literature standard (e.g. de Walque and Wouters (2008) and Smets and Wouters (2007)). For the trade elasticities ϵ and ϵ^* we choose a comparatively wide prior, reflecting the wide range of modern-day estimates for these parameters. The migration parameters ψ and ψ^* determine how sensitive migration is to differences in the utility level between regions: a small ψ implies a stronger migration reaction for any given utility difference, whereas a large ψ implies that migration is largely a random phenomenon.[42] In accordance with the previously cited evidence for the responsiveness of migrants to economic conditions we choose a normal distribution with a relatively small mean of 2. According to current best-practice estimates for the U.S. (Kennan

[39] Since they also depend on estimated parameters, $\bar{o}$ ($\bar{o}^*$), α and α^* are re-calibrated during estimation for each draw from the prior distribution.

[40] The model's steady state for net foreign assets is determined due to migration (see Appendix 4.A.1).

[41] As in Christiano, Trabandt and Walentin (2011), we use the actual sample as our *pre-sample*.

[42] Note that while ψ characterizes migration's sensitivity to cyclical fluctuations, the fixed migration cost κ_d determines the level of migration $\bar{d}$.

and Walker, 2011) a persistent 1% increase in one state's wages implies a 0.5% larger state-population after 5 years. In our model's framework, a value of 2 for ψ implies a similar reactivity of migration.

Nominal rigidity is characterized by the Calvo parameter θ, which together with γ, β and μ determines the slope of the Phillips curve, $\tilde{\kappa}$, according to $\widetilde{\kappa} = (1-\beta\theta)(1-\theta)/[1/\theta(1-\mu+\mu/\gamma)]$. Instead of estimating the Calvo parameters we choose to directly estimate the the Phillips curve slopes. Many modern day quarterly Calvo parameter estimates lie in the range of $[0.5, 0.8]$, which corresponds to an average price duration of 2 to 5 quarters, or a quarterly Phillips curve slope between 0.01 and 0.13. Schmitt-Grohé and Uribe (2004) and Eggertsson (2008) convert the quarterly Phillips curve slope to an annual slope by multiplying the former by four. Thus today's Calvo parameter estimates in the $[0.5, 0.8]$-range imply an annualized Phillips curve slope between 0.04 and 0.52. Where can we expect the corresponding GS parameter to lie? Aggregate price indices exhibited substantially more flexibility (Gordon, 1990; Basu and Taylor, 1999; Obstfeld, 1993) and output responsiveness than today (Bayoumi and Eichengreen, 1996; Bordo, J. and Redish, 2008; Chernyshoff, Jacks and Taylor, 2009).[43] We thus expect to find steeper Phillips curves for the GS era. To be on the safe side however, we chose a conservative beta-prior for $\widetilde{\kappa}$ and $\widetilde{\kappa}^*$, which gives almost equal prior weight to all but the most extreme values of the 0-1 range.

On the monetary side, following Benati et al. (2008) and Fagan, Lothian and McNelis (2013) we assume a prior mean of 0.1 for the interest-rate elasticity of money demand v^r (also see Bae and De Jong, 2007, for similar 1900-1945 estimates for the U.S.). Concerning the sensitivity of gold flows to the exchange rate ϵ^e we remain agnostic except for the sign, by selecting a wide $[0, 15]$ uniform prior distribution. In our prior choice for the portfolio adjustment cost parameter K we select an inverse gamma prior with a mean of 0.04 (see Benigno, 2009), implying an average deviation of H- from F interest rates of 1 ppt. This roughly corresponds to contemporary textbook estimates of an annualized 75 basis point wedge between London and New York interest rates (e.g. Haupt, 1894; Margraff, 1908; Escher, 1917).

For the discount rate rule, we use pre-sample data to inform our prior choice. We set the prior means of the discount rate coefficients close to the pooled regression coefficient estimates that we obtained for a sample of GS members for the years 1870-1879. We then chose wide prior standard deviations to reflect our uncertainty about these parameters. Consistent with historical accounts the regression results also show that the U.K. changed its discount rate much more frequently than the Swedish and Belgian central banks.[44] Accordingly, we estimate the discount rate rule for the U.K. without a persistence term. Furthermore, although foreign

[43]Note however that the micro evidence based on product-group level prices indicates that prices have not become less flexible over time (Kackmeister, 2007; Knotek, 2008). This points towards a compositional effect: it is well known that pre-1913 price indices contain more flex-price items such as agricultural produce and raw materials than today's indices. However, for our macro model calibration the aggregate price level evidence has more relevance.

[44]The Bank of England decided upon its discount rate on a weekly basis (see Eichengreen, Watson and Grossman, 1985).

countries might have wanted to keep their nominal exchange rates stable vis-à-vis the U.K. (see Morys, 2010) there is little reason why they should directly target the nominal exchange rate vis-a-vis Sweden or Belgium. Hence, only for the U.K. model do we include a reaction term for nominal exchange rate deviations into the *F* discount rate function.

Exogenous shocks generally follow AR(1) processes.[45] Only the discount rate shock is not allowed to exhibit any persistence beyond that which is intrinsic to the discount rate rule. All persistence parameters are given a wide beta prior with a mean of 0.3.[46] We allow for the region-specific technology shocks to be correlated. We chose a flat beta prior for the correlation σ_{aa^*}. The persistence and standard deviation of the gold shocks are assumed to be the same across regions.

Finally, we allow for measurement error in all trade-weighted observables (all *F*-aggregates and the NEER). We also allow for measurement error in the net immigration and *trade balance* to *GDP* ratio. Following Christiano, Trabandt and Walentin (2011) we calibrate the measurement errors' variance to 10% of the variance in the observables. As shown in Online Appendix 4.A.5, the data without measurement error very closely follow the original data.

[45]Note that in the case of money demand shocks, it is the changes $\Delta\epsilon_t^x \equiv \eta_t^x$ that follow an AR(1) process.

[46]The 0.3 mean for our annual model corresponds to the conventional prior mean from the $[0.5, 0.85]$ range that is usually applied in quarterly models: $0.3 \approx 0.75^4$.

Table 4.2: *Prior distribution*

	Description	Distribution	Mean	S.D.
Utility parameters				
σ_c	Inverse EIS	Normal	1.50	0.35
σ_l	Inverse Frisch elasticity	Normal	2.00	0.75
ϵ	Trade elasticity (H)	Normal	1.50	1.50
ϵ^*	Trade elasticity (F)	Normal	1.50	1.50
Migration parameters				
ψ	Migration sensitivity (H)	Normal	2.00	1.00
ψ^*	Migration sensitivity (F)	Normal	2.00	1.00
Price parameters				
$\tilde{\kappa}$	Phillips curve slope (H)	Beta	0.50	0.28
$\tilde{\kappa}^*$	Phillips curve slope (F)	Beta	0.50	0.28
Gold flow parameters				
ϵ^e	Gold flow due to exchange rate	Uniform	[0, 15]	
$\frac{\bar{G}}{\bar{G}^*}$	Relative gold stock	Inv. gamma	$\frac{n}{1-n}$	1.00
Discount rate parameters				
ρ	Discount rate persistence (H)	Beta	0.30	0.15
Φ^y	Output coefficent (H)	Beta	1.00	0.56
Φ^e	Exchange rate coefficent (H)	Beta	1.00	0.56
Φ^g	Cover ratio coefficient (H)	Beta	1.00	0.56
ρ^*	Discount rate persistence (F)	Beta	0.30	0.15
Φ^{y*}	Output coefficent (F)	Beta	1.00	0.56
Φ^{e*}	Exchange rate coefficent (F)	Beta	1.00	0.56
Φ^{g*}	Cover ratio coefficient (F)	Beta	1.00	0.56
Other parameters				
K	Foreign portfolio adjustment costs	Inv. gamma	0.04	2.00
v^r	Interest rate elasticity of money demand	Inv. gamma	0.10	0.03

	Description	Distribution	Mean	S.D.
Shock parameters				
ρ^a	Persistence, technology (H)	Beta	0.30	0.15
ρ^{a*}	Persistence, technology (F)	Beta	0.30	0.15
ρ_g	Persistence, markup (H)	Beta	0.30	0.15
ρ^{g*}	Persistence, markup (F)	Beta	0.30	0.15
ρ^x	Persistence, money demand (H)	Beta	0.30	0.15
ρ^{x*}	Persistence, money demand (F)	Beta	0.30	0.15
ρ^b	Persistence, risk premium (H)	Beta	0.30	0.15
ρ^{b*}	Persistence, risk premium (F)	Beta	0.30	0.15
ρ^m	Persistence, gold (H & F)	Beta	0.30	0.15
η^a	S.D., technology (H)	Inv. gamma	0.50	2.00
η^{a*}	S.D., technology (F)	Inv. gamma	0.50	2.00
η^g	S.D., markup (H)	Inv. gamma	0.50	2.00
η^{g*}	S.D., markup (F)	Inv. gamma	0.50	2.00
η^x	S.D., money demand (H)	Inv. gamma	0.50	2.00
η^{x*}	S.D., money demand (F)	Inv. gamma	0.50	2.00
η^b	S.D., risk premium (H)	Inv. gamma	0.50	2.00
η^{b*}	S.D., risk premium (F)	Inv. gamma	0.50	2.00
η^r	S.D., monetary policy (H)	Inv. gamma	0.10	2.00
η^{r*}	S.D., monetary policy (F)	Inv. gamma	0.10	2.00
η^m	S.D., gold (H & F)	Inv. gamma	0.50	2.00
σ_{aa^*}	Correlation, technology	Beta	0.50	0.28

Notes: EIS – elasticity of intertemporal substitution. S.D. – standard deviation. The prior distributions for $\psi, \psi^*, \sigma_l, \epsilon$ and ϵ^* are truncated at zero. In case of the U.K., ρ is not estimated but set to zero. In the case of Sweden and Belgium, Φ^{e*} is not estimated but set to zero.

4.5.4. *Posterior distribution*

Table 4.5.5 summarizes the estimation results. Firstly, the posterior distributions for the Phillips curve parameters indicate that the price level was much more flexible in the time before 1914 than it is today. Annual Phillips curve (PC) slope estimates for the U.K., Sweden and Belgium are 0.34, 0.53 and 0.90 respectively, implying average price durations in the 1.5 to 2 quarter range. For comparison, estimates for the U.S. and the euro area today generally hint towards a much flatter Phillips curve. The Calvo parameter estimates obtained by de Walque and Wouters (2008) and Smets and Wouters (2003, 2007) for instance, imply annualized Phillips curve slopes in the [0.01-0.15]-range.

Secondly, consider the parameters ψ and ψ^* that pin down the sensitivity of migration to the business cycle. As expected, the comparatively small estimate for Sweden reflects that Swedish migrants were very responsive to economic fundamentals. Though less than in Sweden, U.K. migrants still responded strongly to cyclical differences in consumption and labor income. Given the U.K.'s ψ-estimate, a persistent 1% decrease in consumption in the U.K. relative to the F-region would result in a 4% decrease in the U.K.'s population after 5 years. By contrast, the comparatively high ψ-estimate for Belgium implies that Belgian migration flows were considerably less sensitive.[47]

Finally, the monetary side is characterized by the following parameter estimates: The discount rate policy in all three countries stabilized gold cover ratios ($\phi^g > 0$) and the nominal exchange rate ($\phi^e > 0$), whereas our evidence for output stabilization ($\phi^y > 0$) is restricted to the British and Swedish central banks. In both cases, the policy reaction to output is much less than what a modern-day Taylor rule would suggest ($\Phi^y_{Taylor} = 0.5$). These results reflect that the primary monetary policy targets at the time were stable gold cover ratios and nominal exchange rates. The autocorrelation of Swedish and Belgian discount rates is 0.42 and 0.44 respectively, implying that some interest rate smoothing took place. Furthermore Belgian discount rates reacted less to deviations of the exchange rate from its mint parity ($(1-\rho)\cdot\Phi^e = 0.34$) and fluctuations in the gold cover ratio ($(1-\rho)\cdot\Phi^g = 0.07$). In this sense the National Bank of Belgium made more use of the monetary policy independence that the Gold Standard allowed. Note, however, that it does not appear to have targeted the domestic output gap.

4.5.5. *Model evaluation*

To see whether the estimated models give a good description of the data, we conducted marginal likelihood comparisons between different model versions and extensive moment

[47] Between 1880 and 1913 Belgium itself was a destination for many political refugees, which did not migrate primarily for economic reasons. Furthermore, unlike many other European countries Belgium did not encourage the emigration of its citizens to relieve domestic crises. Finally, overall net immigration relative to the general population level in Belgium was small in the period covered by our sample, 1880-1913.

comparisons of real and simulated data. Note that our baseline model specification does not feature external consumption habits, which is a common feature of DSGEs estimated with modern data. A marginal likelihood comparison of the models with and without habit formation, however, shows that the latter is favored by our 1880-1913 data. Similarly we have also estimated a version of the model with a more elaborate law of motion for central bank gold stocks (see equation 4.4). Strictly speaking gold stocks do not only depend on exchange rate deviations, but also on net immigration (migrants carrying gold coins) and the trade balance (trade deficits being settled through gold transfers). The estimated parameters however, confirm back-of-the-envelope calculations as well as historical narratives in that by the late 19th century these two gold flow determinants were of negligible importance. We thus opted for the more parsimonious version of the model.

Next, we compared the (auto-)correlations of the simulated data to that of the observed data. We did this for the six variables that we are most interested in – a total of 216 moments.[48] To obtain the simulated data we run the model with all parameters set to their posterior mean.[49] Figures 4.22 to 4.24 in Online Appendix 4.A.3 show the correlations, including the 90% coverage percentiles for the stochastic simulations. The model fairly accurately represents the data's correlation structure.

[48]Per capita GDP, inflation, the discount rate, the nominal exchange rate, changes in the net immigration/population ratio and changes in the trade-balance/GDP ratio.

[49]We conducted 2000 simulations. Each simulation has 34 periods, corresponding to the length of our sample. To limit the results' dependence on initial conditions, we ran simulations for 134 periods and discarded the first 100 observations.

Table 4.3: *Posterior distribution*

		U.K.			Sweden			Belgium		
Description		Mean	90% HPDI		Mean	90% HPDI		Mean	90% HPDI	
Utility parameters										
σ_c	Inverse EIS	1.57	1.11	2.03	2.50	2.07	2.93	2.10	1.77	2.41
σ_l	Inverse Frisch elasticity	2.65	1.67	3.60	2.85	1.94	3.79	3.36	2.57	4.13
ϵ	Trade elasticity (H)	2.81	0.71	4.72	1.44	0.09	2.60	0.64	0.03	1.17
ϵ^*	Trade elasticity (F)	3.20	1.57	4.80	1.26	0.26	2.27	0.47	0.00	0.84
Migration parameters										
ϕ	Migration sensitivity (H)	0.27	0.06	0.47	0.07	0.05	0.08	3.77	2.76	4.81
ϕ^*	Migration sensitivity (F)	1.98	0.33	3.39	2.03	0.44	3.52	3.44	2.42	4.40
Price parameters										
$\tilde{\kappa}$	Phillips curve slope (H)	0.34	0.16	0.54	0.53	0.33	0.75	0.90	0.79	1.00
$\tilde{\kappa}^*$	Phillips curve slope (F)	0.35	0.14	0.58	0.64	0.39	0.93	0.36	0.18	0.54
Gold flow parameters										
ϵ^e	Gold flow due to nom. exchange rate	2.33	3.29	1.35	1.85	2.90	0.78	0.54	0.75	0.31
$\frac{\bar{G}}{\bar{G}^*}$	Relative gold stock	0.05	0.04	0.07	0.03	0.01	0.06	0.02	0.01	0.03
Discount rate parameters										
ρ	Discount rate persistence (H)	–	–	–	0.42	0.18	0.65	0.44	0.28	0.59
Φ^y	Output coefficent (H)	0.14	0.09	0.19	0.18	0.01	0.34	0.02	0.00	0.04
Φ^e	Exchange rate coefficent (H)	0.72	0.13	1.27	1.68	1.29	2.00	0.61	0.14	1.07
Φ^g	Cover ratio coefficient (H)	0.05	0.04	0.06	0.14	0.07	0.22	0.12	0.08	0.15
ρ^*	Discount rate persistence (F)	0.25	0.06	0.42	0.42	0.17	0.66	0.13	0.02	0.24
Φ^{y*}	Output coefficent (F)	0.04	0.00	0.09	0.16	0.00	0.33	0.06	0.00	0.13
Φ^{e*}	Exchange rate coefficent (F)	1.63	1.23	2.00	–	–	–	–	–	–
Φ^{g*}	Cover ratio coefficient (F)	0.39	0.21	0.54	0.49	0.17	0.83	0.18	0.10	0.27
Other parameters										
K	Foreign portfolio adjustment costs	0.24	0.01	0.45	0.09	0.02	0.17	0.53	0.34	0.72
υ^r	Interest rate elasticity of money demand	0.10	0.06	0.13	0.10	0.06	0.14	0.10	0.06	0.14

Table 4.4: *Posterior distribution (continued)*

		U.K.			Sweden			Belgium		
Description		Mean	90% HPDI		Mean	90% HPDI		Mean	90% HPDI	
Shock parameters										
ρ^a	Persistence, technology (H)	0.18	0.06	0.29	0.05	0.01	0.09	0.49	0.39	0.59
ρ^{a*}	Persistence, technology (F)	0.93	0.90	0.96	0.86	0.82	0.90	0.46	0.29	0.64
ρ^g	Persistence, markup (H)	0.31	0.10	0.51	0.38	0.24	0.53	0.24	0.08	0.38
ρ^{g*}	Persistence, markup (F)	0.52	0.32	0.73	0.23	0.07	0.38	0.35	0.17	0.52
ρ^x	Persistence, money demand (H)	0.19	0.05	0.33	0.20	0.05	0.34	0.07	0.01	0.13
ρ^{x*}	Persistence, money demand (F)	0.54	0.39	0.69	0.36	0.16	0.56	0.55	0.35	0.74
ρ^b	Persistence, risk premium (H)	0.30	0.07	0.50	0.52	0.29	0.75	0.33	0.12	0.51
ρ^{b*}	Persistence, risk premium (F)	0.24	0.04	0.43	0.34	0.09	0.57	0.30	0.07	0.52
ρ^m	Persistence, gold (H & F)	0.21	0.04	0.38	0.30	0.12	0.49	0.14	0.03	0.26
η^a	S.D., technology (H)	1.52	1.26	1.77	2.05	1.77	2.32	1.62	1.43	1.82
η^{a*}	S.D., technology (F)	0.34	0.25	0.43	0.32	0.26	0.39	0.49	0.37	0.60
η^g	S.D., markup (H)	2.46	1.63	3.25	4.60	3.39	5.80	6.71	5.34	8.03
η^{g*}	S.D., markup (F)	1.34	0.77	1.91	2.11	1.32	2.85	1.51	0.75	2.24
η^x	S.D., money demand (H)	2.76	2.38	3.15	7.35	6.37	8.36	2.09	1.93	2.24
η^{x*}	S.D., money demand (F)	0.75	0.52	0.98	0.93	0.56	1.30	0.33	0.20	0.44
η^b	S.D., risk premium (H)	0.26	0.18	0.34	0.25	0.17	0.32	0.24	0.17	0.31
η^{b*}	S.D., risk premium (F)	0.20	0.13	0.27	0.21	0.13	0.28	0.19	0.13	0.26
η^r	S.D., monetary policy (H)	0.39	0.29	0.49	0.69	0.39	0.97	0.19	0.15	0.23
η^{r*}	S.D., monetary policy (F)	0.38	0.27	0.49	0.31	0.22	0.40	0.28	0.22	0.34
η^m	S.D., gold (H & F)	0.48	0.34	0.62	0.38	0.16	0.60	0.18	0.12	0.23
σ_{aa^*}	Correlation, technology	0.28	0.03	0.49	0.44	0.26	0.61	0.07	0.00	0.15

Notes: HPDI – highest posterior density interval. For the U.K. ρ is not estimated but set to zero. For Sweden and Belgium Φ^{e*} is not estimated but set to zero.

4.6. Counterfactual Analysis

In this section we conduct the horse-race between the price-, migration- and monetary policy-channels to explain why external adjustment under the Gold Standard (GS) was associated with few output costs. In order to quantitatively assess the channels' relative importance we present counterfactual output volatilities. The counterfactual volatilities are obtained from model simulations in which either the price-, the migration- or the monetary policy parameters are set to a counterfactual value of interest. Table 4.5 displays the results of this exercise. The first column shows the standard deviations of the observables under the baseline model. We simulated the model on the basis of the posterior mean of the estimated structural parameters and shock processes. More particularly, we ran 2000 simulations, each 34 periods long (corresponding to the length of our sample).[50] Columns 2 to 4 display the counterfactual standard deviations that result from conducting the same simulation with the respective counterfactual structural parameters.

First, for the price rigidity counterfactual we lower all Phillips curve slope parameters from our high GS estimates to a value which is representative of today's economies. In particular we set the average duration of price contracts to three quarters, implying annualized Phillips curve slopes of 0.13 for the U.K. and 0.17 for Sweden and Belgium. This comes close to what most price rigidity estimates for current advanced economies look like today (see Smets and Wouters, 2007; Schorfheide, 2008). In this scenario the counterfactual standard deviations for per capita output are substantially higher, increasing between 81.5% (for the U.K.) and 145.2% (for Belgium). According to these model simulations flexible prices were a major reason for the resilience of per capita incomes during the GS.

In the second counterfactual, we shut down the migration channel. This had little effect on output volatility. The exception is Belgium, where the standard deviation of output increases by a notable 3.8%. The counterfactual "no migration"-simulations for the U.K. and Belgium even resulted in slightly less volatile per capita incomes. This acts as a reminder that the stabilizing effects of migration on regional output do not necessarily outweigh the destabilizing effects that arise from the redistribution of aggregate demand away from the already recessionary origin-region.

For the monetary policy counterfactual we eliminated the freedom central banks enjoyed in setting their discount rates by assuming that H has to adjust its interest rate to ensure an absolutely fixed exchange rate, while F – a much larger region than H – sets its discount rate as estimated.[51] Column (4) in Table 4.5 shows that this "no independence" counterfactual has the most impact for the U.K. Here, the monetary policy independence that the GS allowed enabled the Bank of England to achieve a 3.2% lower per capita income volatility. A look at the counterfactual impulse response functions furthermore shows that particularly in the

[50] To limit the result's dependence on the initial conditions, we ran each simulation for 134 periods and discarded the first 100 observations.

[51] See Appendix 4.A.1 for details.

short-run monetary policy could exert a non-negligible stabilizing influence (see 4.28 in the Online Appendix). Such short-run dynamics get played down in Table 4.5, which focuses on overall output volatility.[52] We find, however, no evidence that monetary policy substantially helped the adjustment experience of either Sweden or Belgium.

Table 4.5: *Counterfactual per capita output volatilities*

	Baseline model	Counterfactuals				
		Rigid prices	No migration	No indepen-dence	No migration, given rigid prices	No indepen-dence, given rigid prices
	(1)	(2)	(3)	(4)	(3∣2)	(4∣2)
United Kingdom	1.76	3.20	1.75	1.82	3.19	3.42
		(81.50%)	(-0.89%)	(3.19%)	(-0.16%)	(7.03%)
Sweden	1.88	4.26	1.87	1.90	4.28	4.38
		(126.77%)	(-0.20%)	(0.91%)	(0.46%)	(2.82%)
Belgium	0.94	2.29	0.97	0.93	2.29	2.29
		(145.15%)	(3.77%)	(-0.19%)	(-0.01%)	(-0.16%)

Notes: In parenthesis – percentage change in counterfactual S.D. relative to baseline S.D. for (2), (3) and (4), and relative to rigid price counterfactual in columns (3∣2) and (4∣2).

In the context of today's fixed exchange rate regimes an interesting question arises as to whether international migration can alleviate the external adjustment problem given that prices are rigid. To see if migration would be substantially more effective in reducing output and inflation volatility in a rigid price economy, we ran the corresponding counterfactual GS model simulation. The result displayed in column (3∣2) of Table 4.5 does not support this supposition. Shutting down the migration channel in a rigid price economy does not substantially impact output volatilities relative to the rigid price-only counterfactual. Rigid prices somewhat heighten the stabilizing effect that monetary policy has on output (see column (4∣2)), but the total effects still pale in comparison to the direct effects of price flexibility on output volatility .

In summary, our findings put nominal flexibility at the center of the explanation for why external adjustments under the GS were rather benign. The role of migration- and monetary policy in stabilizing per capita output was comparatively small and, in the case of migration, even ambiguous.

4.7. Sectoral structure, price level flexibility and external adjustment

This section provides an in-depth analysis of price flexibility and external adjustment under the GS. Newly compiled disaggregate sectoral data allows us to address the following questions: Why was the aggregate price level so flexible under the GS? Which prices exactly adjusted by

[52] See Angell (1926) for an early publication that points out that the efficacy of discount rate policy for external adjustment is restricted to the short-run.

how much during external adjustments? Was it really an increase in the export of flex-price goods that turned around the current account?

4.7.1. *Sectoral structure and price level flexibility*

A notable feature of the Gold Standard-economies is their large primary sector shares, even among early industrializers. Primary sector products in turn generally exhibit much more flexible prices than industrial goods or services (Bordo, 1980; Han, Penson and Jansen, 1990; Jacks, O'Rourke and Williamson, 2011). Thus, the Gold Standard economies' sectoral structure is a likely reason for the flexibility of the overall price level.[53] Sectoral inflation variances within our 14-country sample line up accordingly: Table 4.6 shows that the growth rates of prices for agricultural goods (variance = 0.51) and raw materials (variance = 0.64) exhibit about twice the volatility of industrial price-growth rates (variance = 0.27) and more than five times the volatility of service prices (variance = 0.10).[54] To get an idea of the relative importance of primary sectors in the period from 1880 to 1913, consider that in our 14-country sample an average of 47% of employment is concentrated in primary sectors, and 30% of value added is generated in them (see Table 4.6). Even the U.K., the most industrialized country of its time, still employed between 10 and 20% of its labor force in agriculture and mining. Among internationally traded goods, agricultural products and raw materials made up an even larger fraction: Within our 14-country sample 67% of all merchandise exports were primary products.[55] Even among early industrializing North Western European countries, primary product exports equalled the amount of manufacture exports (see Lamartine Yates, 1959, pp. 226-32).

A look at disaggregated nominal prices and real (CPI-deflated) exports confirms the crucial

[53]The compositional explanation of pre-1914 flexibility was already put forth by economists in the 1930s (see Humphrey (1937), Mason (1938) and Wood (1938)) as a way of reconciling the wide-spread belief that the general price level had become more rigid (see Means, 1936) with product-level price studies that showed that neither the frequency nor the size of price changes had changed since the late 18th century (Mills, 1927; Humphrey, 1937; Mason, 1938; Bezanson, Gray and Hussey, 1936; Tucker, 1938). The modern literature on price flexibility has extended this aggregation phenomenon into the 21st century (see Kackmeister (2007) and Knotek (2008) on product-level prices, and Backus and Kehoe (1992) and Basu and Taylor (1999) on aggregate price indices).

[54]The high flexibility of agricultural prices has been linked to their supply and demand elasticities, with short-run supply being highly inelastic (Cairnes, 1873). Perishability and storability play a role in this, with less durable products generally exhibiting more flexible prices (Mills, 1927; Telser, 1975; Reagan and Weitzman, 1982). Blanchard (1983) and Basu (1995) link the high number of production stages and roundaboutness of industrial production to the lower flexibility of industrial goods' prices (see Means, 1935, for a related empirical analysis of prices closer to our sample period). Market structure also becomes a factor in that most agricultural goods are traded on auction markets, while industrial goods are more likely to be sold in customer markets where long-term fixed contracts are more common (see Bordo, 1980; Sachs, 1980; Gordon, 1982).

[55]This comes very close to figures by Aparicio, Pinilla and Serrano (2009), according to which 63% of international trade between 1880 and 1939 consisted of primary products. Furthermore, the fraction of primary products in total trade remains surprisingly stable at around two thirds in the period from 1870 to 1913 (see Lewis, 1952).

Table 4.6: *Sectoral structure, export composition and price volatilities*

	Mean	N.obs
Agriculture, value-added share (%)	30	428
Agriculture, employment share (%)	47	238
Agricultural exports, share of total merchandize exports (%)	36	551
Primary exports, share of total merchandize exports (%)	67	517
	Variance	N.obs
Agricultural prices, year-on-year change (%)	0.51	601
Raw material prices, year-on-year change (%)	0.64	578
Industrial prices, year-on-year change (%)	0.27	509
Service prices, year-on-year change (%)	0.10	436

Notes: The number of observations differs due to data availability and frequency. Agricultural employment share figures are commonly decennial data.

role agriculture played for external adjustment under the GS (see Figure 4.3). Agricultural goods dominated the quick fall in domestic prices, and primary products generally dominated the export booms during major CA-reversals.[56] Four years into the adjustment agricultural and raw material exports were both up by 30%. At the same time industrial exports had increased by only 10%.[57] Agricultural exports in particular, dominated the early years of CA-reversals, with exports up by 20% after only two years.[58]

Increasing primary good exports also left their mark on the adjusting economy's sectoral structure. Figure 4.4 depicts the sectoral adjustment that accompanied the export-led external adjustments of the GS economies. The value added (VA) share of the primary sector (predominantly tradable goods producing) increased by close to 2 ppts; so did the agricultural sector labor share (LS). At the same time, the VA shares of the tertiary sector (mostly non-tradable goods producing) tended to decrease by around 1 ppt. The VA share of the secondary sector, which here combines non-tradables (e.g. construction works) as well as tradables (e.g. raw materials and machines), falls by around 0.5 ppts. In terms of absolute real output, tertiary sector production fell up to 15% below trend during major CA-adjustments, while real primary sector production rose up to 10% above its trend level. Secondary sector production tends to closely follow the tertiary sector's path.[59]

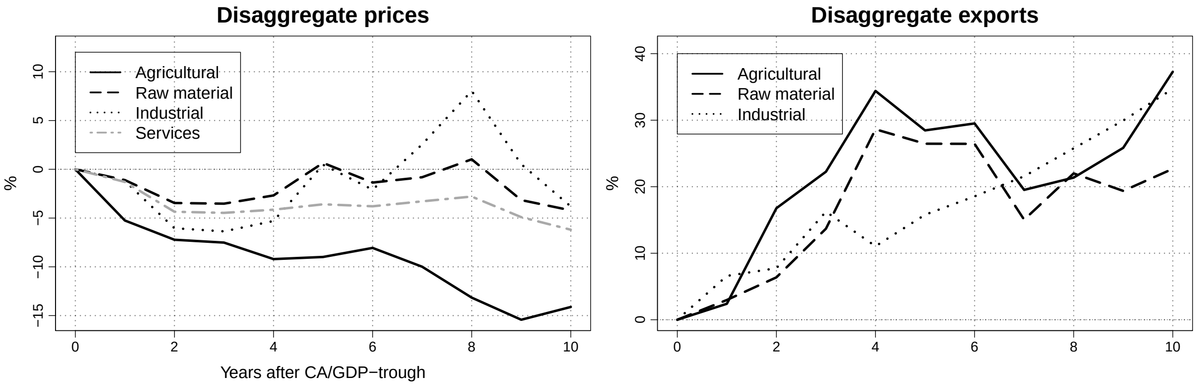
[56] In contrast to industrial and raw material prices the relative decline in agricultural prices is persistent. Note however that $h = 0$ is unlikely to represent a steady state in this case.

[57] Note that while the sharp increase in agricultural exports is accompanied by an equally sharp fall in agricultural prices, this is not the case for raw materials. This possibly hints at differential price elasticities in the international demand for agricultural goods and raw materials.

[58] This relationship between sectoral prices, sectoral exports and the CA/GDP ratio is not restricted to phases of major external adjustment. It also is present in within-year correlations (see Table 4.15 in Online Appendix 4.A.4).

[59] This relationship is robust to an alternative definition of major CA/GDP troughs (see Figure 4.18 in Online Appendix 4.A.3). It also is present outside of major adjustment periods, in the contemporane-

Figure 4.3: *Sectoral prices and sectoral exports after major CA/GDP-reversals relative to non-reversals*



Notes: CA/GDP-troughs are defined according to a turning-point algorithm à la Bry and Boschan (1971): CA/GDP-troughs are defined as the lowest CA/GDP-value in a ±10-year window. The number of CA/GDP-troughs thus identified is nine. The disaggregate export data are CPI-deflated.

In sum, the fortunate coincidence of the nominally most flexible sector – agriculture – also being the most important tradable sector is the main explanation for the ease of external adjustment under the pre-1913 Gold Standard.[60] When hit by a shock that necessitated the reversal of the current account the agricultural sector produced more of its tradable output, which was readily absorbed by world markets.[61]

4.7.2. Terms of trade vs. local prices

While the local price level fell markedly, the terms of trade – the ratio of export prices to import prices as measured at the port – remained stable (Figure 4.5, left graph).[62] This generalizes the observations made by Viner (1924) and Angell (1926) for Canada, and by Wilson (1931) and Pope (1986, 1990) for Australia. They noted that the terms of trade moved little during external adjustments under the GS. How can this well known observation be reconciled with a price flexibility based explanation of external adjustment?

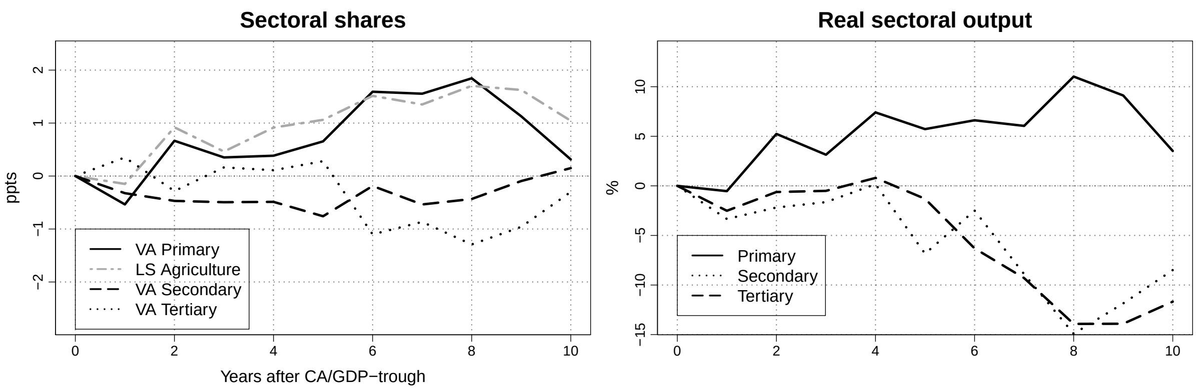
ous correlations of changes in the CA/GDP ratio with changes in the sectoral shares (see Table 4.17 in Online Appendix 4.A.4).

[60] Note that large primary sector shares today are far less associated with benign external adjustments among developing economies (see Labys and Maizels, 1993; Kinda, Mlachila and Ouedraogo, 2016). One explanation may lie in the importance of primary product exports for fiscal revenue. Prior to 1913 government spending only made up a small fraction of GDP and revenue losses from lower-priced agricultural products would primarily be borne by private individuals.

[61] The sectoral adjustment, away from services and towards tradable primary goods, can be easier to accomplish against the backdrop of rapid industrialization. Instead of requiring a costly re-allocation of labor and capital away from the production of non-tradables towards the production of tradables, external adjustments under the GS simply required a temporary slow-down in the secular transition from agriculture (primarily tradable) to industry and services (primarily non-tradable).

[62] The same relationship between the terms of trade, the CPI, and the CA/GDP ratio extends to non-adjustment periods (see the within-year correlations in Table 4.16 in Online Appendix 4.A.4). It also is robust to using all visually salient CA/GDP troughs, instead of the lowest CA/GDP-value in a ±10-year window (see Figure 4.17 in Online Appendix 4.A.3).

Figure 4.4: *Sectoral adjustment after major reversals in the CA/GDP-ratio*



Notes: CA/GDP-troughs are defined according to a turning-point algorithm à la Bry and Boschan (1971): CA/GDP-troughs are defined as the lowest CA/GDP-value in a $\pm$10-year window. The number of CA/GDP-troughs thus identified is nine. VA – value added share. LS – labor share.

To better understand how a stable terms of trade, together with domestic price deflation, can bring about external adjustment it is worth taking a look at the different price components that are involved. The terms of trade (ToT_t) equals export prices ($\tilde{P}^{\star}_{H,t}$) minus import prices ($\tilde{P}_{F,t}$) as measured at the port:

$$\widehat{ToT}_t = \hat{\tilde{P}}^{\star}_{H,t} - \hat{\tilde{P}}_{F,t},$$

where hatted variables denote logarithms.

The log CPI can be written as a weighted sum of non-tradable prices ($P_{N,t}$) and tradable prices ($P_{T,t}$). The latter can be further decomposed into the price of home tradables, as measured at home ($\tilde{P}_{H,t}$), and the price of foreign tradables, as measured at the port ($\tilde{P}_{F,t}$):

$$\begin{aligned} \hat{P}_t &= (1-\breve{\gamma})\hat{P}_{N,t} + \breve{\gamma}\hat{P}_{T,t} \\ &= (1-\breve{\gamma})\hat{P}_{N,t} + \breve{\gamma}\left[\breve{\alpha}\hat{\tilde{P}}_{H,t} + (1-\breve{\alpha})\hat{\tilde{P}}_{F,t}\right], \end{aligned} \tag{4.5}$$

where $\breve{\gamma}$ denotes the weight of non-tradables in the overall consumption basket, and $\breve{\alpha}$ denotes the share of home tradables among all tradables. In this way, the *ToT* and CPI can be decomposed into four price components: $\tilde{P}^{\star}_{H,t}$, $\tilde{P}_{F,t}$, $P_{N,t}$ and $\tilde{P}_{H,t}$.

Table 4.7 summarizes the direction of movement of the four price components during major external adjustments. The table also shows the substitution effect associated with each of these price movements. These substitution effects have been derived from a straightforward extension of our GS model by a tradable and non-tradable sector (the full model description is provided in Appendix 4.A.2).

The export price of H tradable goods ($\tilde{P}^{\star}_{H,t}$) and the import price of F tradable goods ($\tilde{P}_{F,t}$) both fall around 4% two years into the adjustment, resulting in a stable *ToT* (see Figure 4.5). Despite falling by an equal amount, however, the fall in export prices is likely to increase

Figure 4.5: *Terms of trade vs. local prices after major reversals in the CA/GDP-ratio*

Notes: CA/GDP-troughs are defined according to a turning-point algorithm à la Bry and Boschan (1971): CA/GDP-troughs are defined as the lowest CA/GDP-value in a ±10-year window. The number of CA/GDP-troughs thus identified is nine.

exports by more than the equivalent fall in import prices increases imports. This is because the rest of the world is large compared to the local economy.

Next, the local price of H tradable goods ($\tilde{P}_{H,t}$), as indicated by local agricultural prices, falls by a large amount – around 8% two years into the adjustment (see Figure 4.3). This is likely to induce a sizeable fall in imports, as domestic consumers substitute towards the cheaper domestic tradable good.

Also note that the local price of H non-tradable goods ($P_{N,t}$), as indicated by local service prices, falls around 4% (see Figure 4.3). This puts pressure on the CPI, and to the extent that non-tradable inputs enter tradable goods it is part of the explanation for why $\tilde{P}_{H,t}$ and $\tilde{P}^{\star}_{H,t}$ fall.

One loose end remains. Why does the local price of H tradables ($\tilde{P}_{H,t}$) fall by around twice as much as the export price of the very same tradables ($\tilde{P}^{\star}_{H,t}$)? This is consistent with distributional services driving a wedge between local prices and port prices. Consider that selling one ton of grain overseas is associated with more distribution costs (e.g. transportation, warehousing and finding overseas buyers) than selling the same ton of grain locally.[63] If the price for such distribution services is less flexible than the local price for grain, then the port price for grain – an aggregate of distribution service prices and local grain prices – will display fewer fluctuations than the local price for grain.

In sum, falling export prices induce a large increase in exports, while falling import prices and falling local prices have contravening effects on imports. The net result is a stable terms of trade, a sizeable decrease in the domestic price level and a sizeable increase in exports.

4.7.3. *Engel decomposition*

Engel (1993) finds that most variation in the real exchange rate today is due to variation in

[63] Although by the late 19th century important trading centers and coastal cities were internationally well-integrated there was considerable market segmentation further inland (Uebele, 2011).

Table 4.7: *Local prices, terms of trade and the trade balance*

Price	Price change	Substitution effect
$P^{\star}_{H,t}$ (port price of H tradable good)	$\downarrow$	exports $\uparrow\uparrow$
$P_{F,t}$ (port price of F tradable good)	$\downarrow$	imports $\uparrow$
$P_{H,t}$ (local price of H tradable good)	$\downarrow\downarrow$	imports $\downarrow$
Net effects	ToT stable, CPI $\downarrow\downarrow$	exports $\uparrow\uparrow$

tradable goods prices, as opposed to variation in non-tradable goods prices. How does this compare to the GS era? Engel (1993) decomposes the logarithm of the real exchange rate into a tradable price component (q_T), and a non-tradable price component (q_N):

$$\begin{aligned}\widehat{REER}_t &= \widehat{CPI}_t + \widehat{NEER}_t - \widehat{CPI}^{\star}_t \\ &= \underbrace{\widehat{NEER}_t + \hat{P}_{T,t} - \hat{P}^{\star}_{T,t}}_{\equiv q_T} + (1-\check{\gamma})\underbrace{[(\hat{P}_{N,t} - \hat{P}_{T,t}) - (\hat{P}^{\star}_{N,t} - \hat{P}^{\star}_{T,t})]}_{\equiv q_N},\end{aligned}$$

where we have used equation 4.5 to substitute for the CPI terms. $P_{T,t}$ denotes the price of locally consumed tradables, and $P_{N,t}$ denotes the price of local non-tradables. The F region's equivalents are denoted with an asterisk. $NEER_t$ denotes the nominal effective exchange rate and $\check{\gamma}$ denotes the weight of non-tradables in the overall consumption basket. All prices are in logs.[64] Table 4.8 shows how the two components q_T and q_N correlate with the REER. When port prices are used for $P_{T,t}$ and $P^{\star}_{T,t}$ (as suggested by Burstein, Eichenbaum and Rebelo, 2005), the non-tradable price component, q_N, is positively correlated with the REER, while the tradable price component, q_T, is not. This is consistent with the earlier finding that external adjustment under the GS was based on local price deflation.[65] When local prices, instead of port prices, are used to calculate q_T and q_N (see Engel, 1999), the tradable price component q_T starts to exhibit a significantly positive correlation with the REER. However, the correlation coefficient for the non-tradable price component, q_N, remains significantly positive.

In sum, the data indicate that variation in non-tradable prices played an important role in overall REER variation under the GS. This stands in contrast to the findings for floating exchange rate economies today, where most variation in the real exchange rate can be attributed

[64] We use local service prices as an indicator for local non-tradable prices $\hat{P}_{N,t}$. The F region's equivalent, $\hat{P}^{\star}_{N,t}$, is a trade-weighted average of the service prices of all other countries in the sample. With respect to the tradable price $\hat{P}_{T,t}$ two indicators have been used in the literature. First, port prices, as suggested by Burstein, Eichenbaum and Rebelo (2005). In this case, export prices are used as an indicator for the local tradable price $\hat{P}_{T,t}$, while import prices are used for $\widehat{NEER}_t - \hat{P}^{\star}_{T,t}$. Second, we use local tradable prices (see Engel, 1999). In this case we use a weighted average of local agricultural prices and local raw material prices (weighted by value-added sector shares) as our indicator for $\hat{P}_{T,t}$, whereas the F equivalent, $\hat{P}^{\star}_{T,t}$, is a trade-weighted average of the corresponding prices in all other countries.

[65] This finding is also consistent with the finding by Burstein, Eichenbaum and Rebelo (2005) that during several large devaluations in the 1990s and 2000s, variation in q_N accounted for most of the variation in real exchange rates, if port prices are used as the traded goods price.

Table 4.8: *Engel decomposition*

	Port prices: Δ REER				*Local prices:* Δ REER		
	ρ	p	N		ρ	p	N
Δq_T	0.019	0.68	456	Δq_T	0.170***	0.00	287
Δq_N	0.162***	0.00	399	Δq_N	0.107*	0.08	277

Notes: * 0.10 ** 0.05 *** 0.01. ρ: Pearson correlation coefficients. p: p-values. N: number of observations.

to variation in tradable prices q_T, instead of non-tradable prices q_N Engel (1993, 1999).

There exist several plausible explanations for this shift in the composition of real exchange rate movements: First, non-tradable price variation might be more important for economies whose exchange rate is fixed. This conforms with recent findings by Berka, Devereux and Engel (forthcoming), who show that among euro area members, variation in non-tradable prices plays a more important role for overall REER variation. Second, the finding that tradable price variation was less important under the GS than today is also consistent with the fact that tradable goods under the GS (i.e. primary goods) were more homogeneous than tradable goods today. This would be consistent with the finding by Engel (1993), that for very homogeneous tradable goods (e.g. bananas) q_T explains less real exchange rate variation than q_N. In this way, the 20th century shift away from primary goods production may have changed the nature of real exchange rate adjustments. Finally, to the extent that services are labor intensive and wages were less rigid in the late 19th century than they are today, the larger role of non-tradable prices in adjusting the real exchange rate under the GS can be partly attributed to more flexible wages.

4.8. Conclusion

How international adjustment worked so smoothly during the 19th century Gold Standard, a colossus defying most tenets of optimum currency area, has continually fascinated scholars of international economics. The contribution of the present paper towards a better understanding of this benign adjustment experience is twofold. First, we built and estimated a structural model of the Gold Standard. On the basis of the estimated model we quantitatively assessed the relative importance of three prominent adjustment channels: flexible prices, international migration, and monetary policy. Counterfactual simulations suggest that the ease of external adjustment under the Gold Standard was primarily due to flexible prices allowing for speedy expenditure switching.

Second, we find that price flexibility, and thus benign external adjustments, were predicated on a historical contingency: large agricultural sectors and the dominance of primary products among merchandise exports. As still is the case today, agricultural products and raw materials exhibited much more flexible prices than industrial or service goods. At the same time agricultural products made up a large part of all merchandise exports, even among early industrializers. This fortunate coincidence of the nominally most flexible sector simultaneously being the most important tradable sector is the main explanation for the ease of external adjustment under the pre-1913 Gold Standard.

Our findings raise an interesting question with respect to the malfunctioning of the Gold Standard after World War 1 and its fall in the 1930s, which is often attributed to the rise of rigid wages (see Bordo, Erceg and Evans, 2000). A sectoral composition-based explanation for why the 19th century Gold Standard worked well, however, suggests that staying on gold was becoming increasingly difficult as primary sector shares continued their decline. According to this line of reasoning the classical Gold Standard had been approaching its date of expiry independently of the rise of wage rigidity and the unfolding of the tumultuous events after 1913 (see Means, 1936).

Our result also touches upon current problems in the euro area. The pre-1914 Gold Standard is a prime historical example for a functioning fixed exchange rate regime among fiscally independent nation states. In this regard the Gold Standard served as a historical precedent that could be alluded to when the design of the euro area was questioned in principle. To the extent that our findings attribute its functioning to a fortunate historical contingency the Gold Standard loses its role as an exemplar in this regard.

4.A. Appendix

4.A.1. Model appendix

Nonlinear Model

In this section, we present the nonlinear model. In order to save space, we will focus on the Home region where possible. Foreign equations are analogs to the home ones and foreign variables are denoted by an asterisk. Small letters denote real variables defined as $x = X/P$ and $x^* = X^*/P^*$.

We first look at the household decision. The household's two-stage decision involves (i) the migration decision, and (ii) the decision on hours worked, consumption and savings. Households are indexed by i. The migration decision is described by the following equations:

$$\begin{aligned}
\Upsilon_t^i &= \max_{\{\text{stay, migrate}\}} \{V_t^i, \quad V_t^{i^*} + v_t^i - \kappa_d\}, \text{ with } v_t^i \overset{iid}{\sim} Logistic\left(0, \frac{(\pi\psi)^2}{3}\right) \\
d_t^i &= \mathrm{Prob}\,(\,V_t^i \;\leq\; V_t^{i^*} + v_t^i - \kappa_d\,) \\
\Rightarrow \Upsilon_t^i &= \psi \ln\left(\exp\left(\frac{V_t^i}{\psi}\right) + \exp\left(\frac{V_t^{i^*} - \kappa_d}{\psi}\right)\right), \quad d_t^i = \left[1 + \exp\left(\frac{V_t^i - V_t^{i^*} + \kappa_d}{\psi}\right)\right]^{-1}
\end{aligned}$$

The second stage decision is

$$\begin{aligned}
V_t^i \;=\; & \max_{c_t^i,\, l_t^i,\, B_{H,t}^i,\, B_{F,t}^i} \frac{1}{1-\sigma_c}\left(c_t^i - \frac{1}{1+\sigma_l}\, l_t^{i\,1+\sigma_l}\right)^{1-\sigma_c} + \beta\, \mathbb{E}_t\, \Upsilon_{t+1}^i, \\
\text{s.t.} \quad & B_{H,t-1}^i R_{t-1}^e + B_{F,t-1}^i R_{t-1}^{e*}/e_t + TR_t + P_t w_t\, l_t^i + \Gamma_t + I_t^\tau \\
& = B_{H,t}^i + B_{F,t}^i/e_t + P_t\, c_t^i + P_t\, \frac{K}{2}\left(\frac{B^i{}_{F,t}}{P_t\, e_t} - \bar{o}\right)^2
\end{aligned}$$

The budget constraint for a F household is:

$$\begin{aligned}
& B_{H,t-1}^{i*} R_{t-1}^e\, e_t + B_{F,t-1}^{i*} R_{t-1}^{e*} + TR_t^{e*} + P_t^* w_t^*\, l_t^{i*} + \Gamma_t^* + I_t^\tau \\
& = B_{H,t}^{i*}\, e_t + B_{F,t}^{i*} + P_t^*\, c_t^{i*} + P_t^*\, \frac{K}{2}\left(\frac{B_{H,t}^{i*}\, e_t}{P_t^*} - \bar{o}^*\right)^2
\end{aligned}$$

where the nominal exchange rate e_t is expressed in quantity notation, i.e. foreign currency per domestic currency. As explained in the main text, all households within a region make the same decision, hence we drop the household index i. Writing the real exchange rate as

$E_{r,t} = P_t\, e_t / P_t^*$ the first order conditions imply

$$\lambda_t = \left(c_t - \frac{l_t^{1+\sigma_l}}{1+\sigma_l}\right)^{-\sigma_c} \tag{4.A.1}$$

$$\lambda_t^* = \left(c_t^* - \frac{(l_t^*)^{1+\sigma_l}}{1+\sigma_l}\right)^{-\sigma_c} \tag{4.A.2}$$

$$\lambda_t = \beta\, R_t^e\, \mathbb{E}_t \left(\frac{(1-d_{t+1})\ \lambda_{t+1}}{\Pi_{t+1}} + \frac{d_{t+1}\, \lambda_{t+1}^* E_{r,t+1}}{\Pi_{t+1}}\right) \tag{4.A.3}$$

$$\lambda_t^* = \beta\, R_t^{e*}\, \mathbb{E}_t \left(\frac{(1-d_{t+1}^*)\ \lambda_{t+1}^*}{\Pi_{t+1}^*} + \frac{d_{t+1}^*\, \lambda_{t+1}}{\Pi_{t+1}^* E_{r,t+1}}\right) \tag{4.A.4}$$

$$\lambda_t = \beta\, R_t^{e*}\, \frac{1}{1+\mathsf{K}\ (b_{F,t}/E_{r,t} - \bar{o})}\, \frac{e_t}{e_{t+1}} \mathbb{E}_t \left(\frac{(1-d_{t+1})\ \lambda_{t+1}}{\Pi_{t+1}} + \frac{d_{t+1}\, \lambda_{t+1}^* E_{r,t+1}}{\Pi_{t+1}}\right) \tag{4.A.5}$$

$$\lambda_t^* = \beta\, R_t^e\, \frac{1}{1+\mathsf{K}\ \left(b_{H,t}^*\, E_{r,t} - \bar{o}^*\right)}\, \frac{e_{t+1}}{e_t} \mathbb{E}_t \left(\frac{(1-d_{t+1}^*)\ \lambda_{t+1}^*}{\Pi_{t+1}^*} + \frac{d_{t+1}^*\, \lambda_{t+1}}{\Pi_{t+1}^* E_{r,t+1}}\right) \tag{4.A.6}$$

$$l_t^{\sigma_l} = w_t \tag{4.A.7}$$

$$l_t^{*\sigma_l} = w_t^* \tag{4.A.8}$$

The population evolves according to

$$n_t = n_{t-1}\ (1-d_t) + d_t^*\, n_{t-1}^* \tag{4.A.9}$$

$$n_t^* = 1 - n_t \tag{4.A.10}$$

Firm j's optimization problem is

$$\max_{P_{H,t}(j)} \quad \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ (\beta\theta)^k\ \frac{\lambda_{t+k}}{\lambda_t} \frac{P_t}{P_{t+k}} \left[P_{H,t}(j) y_t(j) - w_{t+k} P_{t+k} l_{t+k}(j) \right] \right\} \tag{4.A.11}$$

$$\text{s.t. } y_{t+k}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t+k}}\right)^{-\mu}\ y_{t+k} \tag{4.A.12}$$

$$y_{t+k}(j) = A_{t+k} l_{t+k}^{\gamma} \tag{4.A.13}$$

The first order condition leads to

$$F_t = \lambda_t\, y_t \left(\frac{P_{H,t}}{P_t}\right) \left(\frac{P_{H,t}^{opt}}{P_{H,t}}\right)^{1-\mu} + \beta\,\theta\,\mathbb{E}_t \left(\frac{\left(\frac{P_{H,t}^{opt}}{P_{H,t}}\right)}{\left(\frac{P_{H,t+1}^{opt}}{P_{H,t+1}}\right)} \frac{1}{\Pi_{H,t+1}} \right)^{1-\mu} F_{t+1} \tag{4.A.14}$$

$$K_t = w_t\, \frac{\lambda_t}{\gamma}\, \frac{\mu}{\mu-1} \left(\frac{y_t}{A_t}\right)^{\frac{1}{\gamma}} \left(\frac{P_{H,t}^{opt}}{P_{H,t}}\right)^{\frac{-\mu}{\gamma}} + \beta\,\theta\,\mathbb{E}_t \left(\frac{\left(\frac{P_{H,t}^{opt}}{P_{H,t}}\right)}{\left(\frac{P_{H,t+1}^{opt}}{P_{H,t+1}}\right)} \frac{1}{\Pi_{H,t+1}} \right)^{\frac{-\mu}{\gamma}} K_{t+1} \tag{4.A.15}$$

$$K_t = F_t \tag{4.A.16}$$

The price dynamics are described by

$$1-\theta \left(\frac{1}{\Pi_{H,t}}\right)^{1-\mu} = (1-\theta) \left(\frac{P_{H,t}^{opt}}{P_{H,t}}\right)^{1-\mu} \tag{4.A.17}$$

$$\Delta_t^P = \theta\, \Delta_{t-1}^P\, \Pi_{H,t}^{\frac{\mu}{\gamma}} + (1-\theta) \left(\frac{P_{H,t}^{opt}}{P_{H,t}}\right)^{\frac{(-\mu)}{\gamma}} \tag{4.A.18}$$

where $\Delta_t^P = \frac{1}{n}\int_0^n \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{\frac{-\mu}{\gamma}} dj$ denotes the price dispersion. The monetary side of the model is described by the following four equations

$$R_t = \bar{R}^{1-\rho}\, R_{t-1}^{\rho} \left(\frac{y_t}{\bar{y}}\right)^{(1-\rho)\,\Phi^y} \left(\frac{\gamma_t}{\bar{\gamma}}\right)^{(1-\rho)\,\Phi_g} \left(\frac{e_t}{\bar{e}}\right)^{-(1-\rho)\,\Phi_e} \tag{4.A.19}$$

$$P_{H,t}\; n\, y_t = \exp(\chi_t)\, M_t\, k(R_t) \tag{4.A.20}$$

$$G_t = G_{t-1} + F(e_t)\exp(\epsilon_{m,t}) \tag{4.A.21}$$

$$\gamma_t M_t = P_g G_t, \tag{4.A.22}$$

The market clearing conditions are

$$y_t\, n = (1-\alpha) \left(\frac{P_{H,t}}{P_t}\right)^{-\epsilon} c_t\, n_t + \alpha^* \left(\frac{P_{H,t}^\star}{P_t^\star}\right)^{-\epsilon^\star} c_t^*\, n_t^* \tag{4.A.23}$$

$$\Delta_t^P\, n\, y_t^{\frac{1}{\gamma}} = l_t\, n_t\, A_t^{\frac{1}{\gamma}} \tag{4.A.24}$$

$$0 = n_t\, B_{H,t} + n_t^*\, B_{H,t}^* \tag{4.A.25}$$

$$0 = n_t\, B_{F,t} + n_t^*\, B_{F,t}^* \tag{4.A.26}$$

Auxiliary variables:

$$ToT_t = \frac{P^{\star}_{H,t}}{P_{F,t}} \tag{4.A.27}$$

$$\Pi_t = \frac{P_t}{P_{t-1}} \tag{4.A.28}$$

$$\Pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}} \tag{4.A.29}$$

$$TB_t = n^*_t c^*_{H,t} P_{H,t} - n_t c_{F,t} P_{F,t} \tag{4.A.30}$$

$$c_{H,t} = (1-\alpha)\left(\frac{P_{H,t}}{P_t}\right)^{-\epsilon} c_t \tag{4.A.31}$$

$$c^*_{H,t} = \alpha^*\left(\frac{P^*_{H,t}}{P^*_t}\right)^{-\epsilon^*} c^*_t \tag{4.A.32}$$

$$c_{F,t} = \alpha\left(\frac{P_{F,t}}{P_t}\right)^{-\epsilon} c_t \tag{4.A.33}$$

$$c^*_{F,t} = (1-\alpha^*)\left(\frac{P^*_{F,t}}{P^*_t}\right)^{-\epsilon^*} c^*_t \tag{4.A.34}$$

Steady State

We log-linearize the nonlinear model around a steady state with zero inflation, constant population and $\beta R = 1$. Steady state values are denoted by a bar symbol. From (4.A.4) and (4.A.6) it follows that $\bar{R} = \bar{R}^*$. Using (4.A.4) and (4.A.5) we have $\frac{\beta \bar{R}^* \bar{d}^*}{1-\beta \bar{R}^*(1-\bar{d}^*)} = \frac{1-\beta \bar{R}(1-\bar{d})}{\beta \bar{R} \bar{d}}$. It is easy to see that $\beta \bar{R} = 1$, a standard assumption in the literature, is a solution to the equation. We also have

$$\bar{\lambda}/\bar{E}_r = \bar{\lambda}^* \tag{4.A.35}$$

$$\bar{\lambda} = \left(\bar{c} - \frac{\bar{l}^{1+\sigma_l}}{1+\sigma_l}\right)^{-\sigma_c} \tag{4.A.36}$$

$$\bar{\lambda}^* = \left(\bar{c}^* - \frac{(\bar{l}^*)^{1+\sigma_l}}{1+\sigma_l}\right)^{-\sigma_c} \tag{4.A.37}$$

From (4.A.15), (4.A.16), and (4.A.16) and the corresponding equations for F, we obtain

$$\bar{w} = \gamma \, \bar{y} \, \frac{\bar{P}_H}{\bar{P}} \left(\frac{\bar{y}}{\bar{A}}\right)^{-1/\gamma} \frac{\mu - 1}{\mu} \tag{4.A.38}$$

$$\bar{w}^* = \gamma \, \bar{y}^* \, \frac{\bar{P}_F^*}{\bar{P}^*} \left(\frac{\bar{y}^*}{\bar{A}^*}\right)^{-1/\gamma} \frac{\mu - 1}{\mu} \tag{4.A.39}$$

The steady state labor supply satisfies

$$\bar{l}_l^{\sigma} = \bar{w} \tag{4.A.40}$$

$$(\bar{l}^*)^{\sigma_l} = \bar{w}^* \tag{4.A.41}$$

At the steady state, the asset pooling assumption gives us

$$\bar{n}\,\bar{b} = n\,(1-\bar{d})\,(\bar{b}_H \bar{R} + \bar{b}_F \bar{R}/\bar{E}_r) \, + \, \bar{d}^*\,(1-\bar{n})\,(\bar{b}_H^* \bar{R} + \bar{b}_F^* \bar{R}/\bar{E}_r)$$

$$(1-\bar{n})\,\bar{b}^* = (1-\bar{n})\,(1-\bar{d}^*)\,(\bar{b}_F^* \bar{R} + \bar{b}_H^* \bar{R}\bar{E}_r) \, + \, \bar{d}\,\bar{n}\,(\bar{b}_F \bar{R} + \bar{b}_H \bar{R}\bar{E}_r)$$

Using the steady state bond market clearing conditions and writing real net foreign assets as $\bar{\Omega} \equiv \bar{b}_H + \bar{b}_F/\bar{E}_r$, we have

$$\bar{n}\,\bar{b} = \bar{R}\,(1-\bar{d}-\bar{d}^*)\,\bar{\Omega}\bar{n}$$

$$(1-\bar{n})\,\bar{b}^*/\bar{E}_r = -\bar{R}\,(1-\bar{d}-\bar{d}^*)\,\bar{\Omega}\bar{n}$$

The budget constraints of the households in H and F give us $\bar{\Omega} = \frac{1}{(1-\bar{d}-\bar{d}^*)\,\bar{R}-1} \left(\bar{c} - \frac{\bar{P}_H}{\bar{P}}\bar{y}\right)$, and also

$$\bar{n}\,\frac{\bar{P}_H}{\bar{P}}\bar{y} + (1-\bar{n})\,\frac{\bar{P}_F^*}{\bar{P}^*}\bar{y}^*/\bar{E}_r = \bar{n}\,\bar{c} + (1-\bar{n})\,\bar{c}^*/\bar{E}_r \tag{4.A.42}$$

which reflects the resources constraint of the whole economy in terms of H currency. The goods and labor market clearing conditions imply

$$
\begin{aligned}
\bar{y}\,\bar{n} &= (1-\alpha)\,\left(\frac{\bar{P}_H}{\bar{P}}\right)^{-\epsilon}\,\bar{c}\,\bar{n} + \alpha^*\,\left(\frac{\bar{P}_H\,\bar{E}_r}{\bar{P}}\right)^{-\epsilon^\star}\,\bar{c}^*\,(1-\bar{n}) && (4.A.43)\\
\bar{y}^*\,(1-\bar{n}) &= \alpha\,\left(\frac{\bar{P}_F^*}{\bar{P}^*\,E_r}\right)^{-\epsilon^\star}\,\bar{c}\,\bar{n} + (1-\alpha^*)\,\left(\frac{\bar{P}_F^*}{\bar{P}^*}\right)^{-\epsilon^\star}\,(1-\bar{n})\,\bar{c}^* && (4.A.44)\\
\bar{y} &= \bar{A}\,\bar{l}^{\gamma} && (4.A.45)\\
\bar{y}^* &= \bar{A}^*\,(\bar{l}^*)^{\gamma} && (4.A.46)
\end{aligned}
$$

Prices in the steady state satisfy

$$
1 = (1-\alpha)\,\left(\frac{\bar{P}_H}{\bar{P}}\right)^{1-\epsilon} + \alpha\,\left(\frac{\bar{P}_{F^*}}{\bar{P}^*\,\bar{E}_r}\right)^{1-\epsilon} \qquad (4.A.47)
$$

Finally, the steady state populations satisfy $\bar{d}\,\bar{n} = \bar{d}^*\,(1-\bar{n})$. We solve for $\bar{c}$, $\bar{c}^*$, $\bar{E}_r$, $\frac{\bar{P}_H}{\bar{P}}$, $\frac{\bar{P}_F^*}{\bar{P}^*}$, $\bar{y}$, $\bar{y}^*$, $\bar{l}$, $\bar{l}^*$, $\bar{\lambda}$, $\bar{\lambda}^*$, $\bar{w}$, $\bar{w}^*$ using equations (4.A.35) - (4.A.47).

Log-linearized Model

In this section, we present the complete log-linearized model equation system that is used in the Bayesian estimation. Lower-case variables with a hat symbol represent logarithmic deviations from the steady state value of the variable (denoted by a bar symbol, $\hat{x} = \log\left(\frac{x}{\bar{x}}\right)$). Δ indicates the first difference ($\Delta\widehat{x}_t = \widehat{x}_t - \widehat{x}_{t-1}$). $\widetilde{\kappa}$ denotes the slope of the Phillips curve, which is related to the structural parameters β, γ, μ and θ according to $\widetilde{\kappa} = (1-\beta\theta)(1-\theta)/[1/\theta(1-\mu+\mu/\gamma)]$. We introduce also $\hat{\Omega} \equiv \bar{b}_H\hat{b}_{H,t} + \bar{E}_t\bar{b}_F\hat{b}_{F,t}$.

$$\hat{\lambda}_t = \frac{(-\sigma_c)}{\bar{c}\,(1-h) - \frac{1}{1+\sigma_l}\,(\bar{l})^{1+\sigma_l}}\,\left(\bar{c}\,\hat{c}_t - (\bar{l})^{1+\sigma_l}\,\hat{l}_t\right) \tag{4.A.48}$$

$$\hat{\lambda}^*_t = \frac{(-\sigma_c)}{(1-h)\,\bar{c}^* - \frac{1}{1+\sigma_l}\,(\bar{l}^*)^{1+\sigma_l}}\,\left(\bar{c}^*\,\hat{c}^*_t - (\bar{l}^*)^{1+\sigma_l}\,\hat{l}^*_t\right) \tag{4.A.49}$$

$$\hat{\lambda}_t = \widehat{R}^e_t - \mathbb{E}_t\widehat{\Pi}_{t+1} + \left(1-\bar{d}\right)\,\mathbb{E}_t\hat{\lambda}_{t+1} + \bar{d}\,\left(\mathbb{E}_t\hat{\lambda}^*_{t+1} + \mathbb{E}_t\widehat{E}_{r,t+1}\right) \tag{4.A.50}$$

$$\hat{\lambda}^*_t = \hat{R}^{e*}_t - \mathbb{E}_t\widehat{\Pi}^*_{t+1} + \hat{\lambda}^*_{t+1}\,\left(1-\bar{d}^*\right) + \bar{d}^*\,\left(\mathbb{E}_t\hat{\lambda}_{t+1} - \mathbb{E}_t\widehat{E}_{r,t+1}\right) \tag{4.A.51}$$

$$\hat{R}^e_t = \hat{R}^{e*}_t - \mathbb{E}_t\hat{e}_{t+1} + \hat{e}_t - \frac{\mathsf{K}\,n}{n + 1/\bar{E}_r\,(1-n)}\,\left(\widehat{\Omega}_t - \left(\bar{b}_F/\bar{E}_r - \bar{b}_H\right)\,\widehat{E}_{rt} + \bar{b}_H\,\left(\hat{n}_t - \hat{n}^*_t\right)\right) \tag{4.A.52}$$

$$\begin{aligned}
&\bar{b}\,\left(\hat{n}_{t-1} + \frac{1}{\bar{b}_F/\bar{E}_r + \bar{b}_H}\,\left(\widehat{\Omega}_{t-1} + \bar{b}_H\,\left(\hat{R}_{t-1} - \hat{\Pi}_t\right) + \bar{b}_F/\bar{E}_r\,\left(-\hat{E}_{rt} + \hat{R}^*_{t-1} - \hat{\Pi}^*_t\right)\right)\right.\\
&\left.-\frac{1}{1-\bar{d}-\bar{d}^*}\,\left(\bar{d}\,\hat{d}_t + \bar{d}^*\,\hat{d}^*_t\right)\right) = \widehat{\Omega}_t - \bar{y}\,\frac{\bar{P}_H}{\bar{P}}\,\left(\hat{y}_t + \alpha\left(\frac{\bar{P}_F}{\bar{P}}\right)^{1-\epsilon}\widehat{ToT}_t\right)\\
&+\hat{n}_t\,\left(\bar{c} + \bar{b}_F/\bar{E}_r + \bar{b}_H\right) - \bar{b}_F/\bar{E}_r\hat{E}_{rt} + \bar{c}\,\hat{c}_t
\end{aligned} \tag{4.A.53}$$

$$\hat{d}_t = \left(1-\bar{d}-\bar{d}^*\right)\,\beta\,\mathbb{E}_t\hat{d}_{t+1} + \frac{1-\bar{d}}{\psi}\,\left(\left(\bar{c}^*\,\left(\hat{c}^*_t - h\,\hat{c}^*_{t-1}\right) - (\bar{l}^*)^{1+\sigma_l}\,\hat{l}^*_t\right)\,\bar{\lambda}^* - \left(\bar{c}\,(\hat{c}_t - h\,\hat{c}_{t-1}) - (\bar{l})^{1+\sigma_l}\,\hat{l}_t\right)\,\bar{\lambda}\right) \tag{4.A.54}$$

$$\hat{d}^*_t = \left(1-\bar{d}-\bar{d}^*\right)\,\beta\,\mathbb{E}_t\hat{d}^*_{t+1} - \left(\left(\bar{c}^*\,\left(\hat{c}^*_t - h\,\hat{c}^*_{t-1}\right) - (\bar{l}^*)^{1+\sigma_l}\,\hat{l}^*_t\right)\,\bar{\lambda}^* - \left(\bar{c}\,(\hat{c}_t - h\,\hat{c}_{t-1}) - (\bar{l})^{1+\sigma_l}\,\hat{l}_t\right)\,\bar{\lambda}\right)\,\frac{1-\bar{d}^*}{\psi^*} \tag{4.A.55}$$

$$\hat{n}_t = \left(1-\bar{d}\right)\,\hat{n}_{t-1} + \bar{d}\,\hat{n}^*_{t-1} - \bar{d}\,\hat{d}_t + \bar{d}\,\hat{d}^*_t \tag{4.A.56}$$

$$\hat{n}^*_t = \hat{n}_t\,\frac{-n}{1-n} \tag{4.A.57}$$

$$\hat{\Pi}_{H,t} = \beta\,\mathbb{E}_t\hat{\Pi}_{H,t+1} + \tilde{\kappa}\,\left(-\alpha\left(\frac{\bar{P}_F}{\bar{P}}\right)^{1-\epsilon}\widehat{ToT}_t - \hat{y}_t + \hat{w}_t + \frac{1}{\gamma}\,\left(\hat{y}_t - \hat{A}_t\right)\right) + \epsilon^g_t \tag{4.A.58}$$

$$\hat{\Pi}_{F,t} = \beta\, \mathbb{E}_t \hat{\Pi}_{F,t+1} + \tilde{\kappa} \left(\widehat{ToT}_t \left(\alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*} \right)^{1-\epsilon^*} \right) - \hat{y}_t^* + \hat{w}_t^* + \frac{1}{\gamma} \left(\hat{y}_t^* - \hat{A}_t^* \right) \right) + \epsilon_t^{g*} \tag{4.A.59}$$

$$\widehat{ToT}_t \left(1 - \alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*} \right)^{1-\epsilon^*} - \alpha \left(\frac{\bar{P}_F}{\bar{P}} \right)^{1-\epsilon} \right) = \hat{E}_{r,t} \tag{4.A.60}$$

$$\hat{\Pi}_{H,t} = \hat{\Pi}_t + \alpha \left(\frac{\bar{P}_F}{\bar{P}} \right)^{1-\epsilon} \left(\widehat{ToT}_t - \widehat{ToT}_{t-1} \right) \tag{4.A.61}$$

$$\hat{\Pi}_{F,t} = \hat{\Pi}_t^* - \alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*} \right)^{1-\epsilon^*} \left(\widehat{ToT}_t - \widehat{ToT}_{t-1} \right) \tag{4.A.62}$$

$$\begin{aligned} \hat{y}_t = {} & \frac{\bar{c}}{\bar{y}} \left(1 - \alpha\right) \frac{\bar{P}_H}{\bar{P}}^{-\epsilon} \left(\hat{c}_t + \hat{n}_t\right) + \frac{\frac{(1-n)\, \bar{c}^* \, \frac{\bar{P}_H}{\bar{P}}^{-\epsilon}}{n}}{\bar{y} \bar{E}_r^{\epsilon}} \alpha^* \left(\hat{c}_t^* + \hat{n}_t^* - \hat{E}_{rt}\, \epsilon \right) \\ & - \widehat{ToT}_t \frac{\frac{\alpha \left(\frac{\bar{P}_F}{\bar{P}} \right)^{1-\epsilon}}{n}}{\bar{y}} \left(\frac{\bar{P}_H}{\bar{P}}^{-\epsilon} \left(1 - \alpha\right) n\, \bar{c}\, \epsilon + 1/\bar{E}_r^{\epsilon}\, \alpha^* \left(1 - n\right) \frac{\bar{P}_H}{\bar{P}}^{-\epsilon} \bar{c}^*\, \epsilon \right) \end{aligned} \tag{4.A.63}$$

$$\begin{aligned} \hat{y}_t^* = {} & \left(\hat{c}_t^* + \hat{n}_t^* \right) \frac{\bar{c}^*}{\bar{y}^*} \left(1 - \alpha^*\right) \frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} + \frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} \frac{\alpha\, \frac{\bar{c}\, n}{1-n} \bar{E}_r^{\epsilon}}{\bar{y}^*} \left(\hat{c}_t + \hat{n}_t + \hat{E}_{rt}\, \epsilon \right) \\ & + \widehat{ToT}_t \frac{\frac{\alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*} \right)^{1-\epsilon^*}}{1-n}}{\bar{y}^*} \left(\frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} \left(1 - \alpha^*\right) \left(1 - n\right) \bar{c}^*\, \epsilon + \frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} \alpha\, n\, \bar{c}\, \epsilon \bar{E}_r^{\epsilon} \right) \end{aligned} \tag{4.A.64}$$

$$\hat{R}_t = \hat{R}_{t-1}\, \rho^R + \hat{y}_t \left(1 - \rho^R\right) \Phi^y - \hat{e}_t \left(1 - \rho^R\right) \Phi^e - \left(1 - \rho^R\right) \Phi^g \hat{\gamma}_t + \epsilon_t^r \tag{4.A.65}$$

$$\hat{R}_t^* = \hat{R}_{t-1}^*\, \rho^{R^*} + \hat{y}_t^* \left(1 - \rho^{R^*}\right) \Phi^{y^*} + \left(1 - \rho^{R^*}\right) \Phi^{e^*} \hat{e}_t - \left(1 - \rho^{R^*}\right) \Phi^{g^*} \hat{\gamma}_t^* + \epsilon_t^{r*} \tag{4.A.66}$$

$$\hat{R}_t^e = \hat{R}_t + \epsilon_t^b \tag{4.A.67}$$

$$\hat{R}_t^{e*} = \hat{R}_t^* + \epsilon_t^{b*} \tag{4.A.68}$$

$$\Delta \hat{G}_t \frac{\frac{\bar{G}}{\bar{G}^*}}{1 + \frac{\bar{G}}{\bar{G}^*}} = \hat{e}_t\, \epsilon^e + \epsilon_t^m \tag{4.A.69}$$

$$\Delta \hat{G^*}_t \frac{1}{1 + \frac{\bar{G}}{\bar{G}^*}} = \hat{e}_t \left(-\epsilon^e \right) + \epsilon_t^{m*} \tag{4.A.70}$$

$$\Delta \widehat{M}_t = \hat{y}_t + \hat{\Pi}_{H,t} - \hat{y}_{t-1} - v^r \left(\widehat{R}_t - \widehat{R}_{t-1} \right) - \Delta \epsilon_t^{\chi} \tag{4.A.71}$$

$$\Delta \widehat{M}{*}_t = \hat{\Pi}_{F,t} + \hat{y}_t^* - \hat{y}_{t-1}^* - v^r \left(\widehat{R}_t^* - \widehat{R}_{t-1}^* \right) - \Delta \epsilon_t^{\chi*} \tag{4.A.72}$$

$$\hat{\gamma}_t = \Delta\widehat{G}_t + \hat{\gamma}_{t-1} - \Delta\widehat{M}_t \tag{4.A.73}$$

$$\hat{\gamma}^*_t = \Delta\widehat{G}^*{}_t + \hat{\gamma}^*_{t-1} - \Delta\widehat{M}^*_t \tag{4.A.74}$$

$$\hat{E}_{r,t} = \hat{\Pi}^*_t - \hat{e}_t - \hat{E}_{rt-1} + \hat{e}_{t-1} - \hat{\Pi}_t \tag{4.A.75}$$

$$\hat{t}b_t\,\bar{t}\bar{b} = \left(\hat{y}_t + \widehat{ToT}_t\,\alpha\left(\frac{\bar{P}_F}{\bar{P}}\right)^{1-\epsilon}\right) n\,\bar{y}\,\frac{\bar{P}_H}{\bar{P}} - (\hat{c}_t + \hat{n}_t)\;\bar{c}\,n \tag{4.A.76}$$

$$\hat{n}_t - \hat{n}_{t-1} = \bar{d}\,\left(\hat{d}^*_t + \hat{n}^*_{t-1} - \hat{d}_t - \hat{n}_{t-1}\right) \tag{4.A.77}$$

$$\hat{n}^*_t - \hat{n}^*_{t-1} = \bar{d}^*\,\left(\hat{n}_{t-1} + \hat{d}_t + \left(-\hat{d}^*_t\right) - \hat{n}^*_{t-1}\right) \tag{4.A.78}$$

$$\hat{w}_t = \sigma_l\,\hat{l}_t \tag{4.A.79}$$

$$\hat{w}^*_t = \sigma_l\,\hat{l}^*_t \tag{4.A.80}$$

$$\hat{l}_t = \frac{1}{\gamma}\,\left(\hat{y}_t - \hat{A}_t\right) - \hat{n}_t \tag{4.A.81}$$

$$\hat{l}^*_t = \frac{1}{\gamma}\,\left(\hat{y}^*_t - \hat{A}^*_t\right) - \hat{n}^*_t \tag{4.A.82}$$

$$\hat{A}_t = \rho^a\,\hat{A}_{t-1} - \eta^A_t \tag{4.A.83}$$

$$\hat{A}^*_t = \rho^{a^*}\,\hat{A}^*_{t-1} - \eta^{A^*}_t \tag{4.A.84}$$

$$\epsilon^r_t = \rho^{\epsilon^R}\,\epsilon^r_{t-1} - \eta^R_t \tag{4.A.85}$$

$$\epsilon^{r*}_t = \rho^{\epsilon^{R*}}\,\epsilon^{r*}_{t-1} - \eta^{R^*}_t \tag{4.A.86}$$

$$\epsilon^g_t = \rho^g\,\epsilon^g_{t-1} - \eta^g_t \tag{4.A.87}$$

$$\epsilon^{g*}_t = \rho^{g^*}\,\epsilon^{g*}_{t-1} - \eta^{g^*}_t \tag{4.A.88}$$

$$\epsilon^m_t = \rho_m\,\epsilon^m_{t-1} - \eta^m_t \tag{4.A.89}$$

$$\epsilon^{m*}_t = \rho^*_m, \epsilon^{m*}_{t-1} - \eta^{m*}_t \tag{4.A.90}$$

$$\epsilon^\chi_t = \rho^x\,\epsilon^\chi_{t-1} - \eta^x_t \tag{4.A.91}$$

$$\epsilon^{\chi*}_t = \rho^{x*}\,\epsilon^{\chi*}_{t-1} - \eta^{x*}_t \tag{4.A.92}$$

For the monetary policy counterfactual (*no independence*) we eliminated the freedom central banks enjoyed in setting their discount rates by assuming that H has to adjust its interest rate to ensure an absolutely fixed exchange rate, while F – a much larger region than H – sets its discount rate as estimated. In particular, we substitute the monetary policy equation in the baseline model (equation 4.A.19) by the following equation

$$\widehat{R}_t^e \quad = \quad \widehat{R}_t^{e*} - \frac{Kn}{n + \bar{E}_r\,(1-n)}\left[\bar{b}_H\left(\widehat{b}_{H,t} - \widehat{E}_{r,t} + \widehat{n}_t - \widehat{n}_t^*\right) + \bar{b}_F\bar{E}_r\left(\widehat{b}_{F,t} + \widehat{E}_{r,t}\right)\right] + \tilde{\phi}_e\hat{e}_t \quad ,$$

The last term ($\tilde{\phi}_e > 0$) is necessary to ensure $\hat{e}_t = 0$ (see Benigno and Benigno, 2008). In our counterfactual, we assume $\tilde{\phi}_e = 0.01$.

4.A.2. An extended model with sectoral structure

This section presents an extended GS model that explicitly models a tradable and non-tradable goods producing sector. The model throws light on two salient features of external adjustment under the GS: First, external adjustment under the GS was closely intertwined with its sectoral structure. Second, the terms of trade remained relatively stable during external adjustments under the GS, while the domestic price level deflated. This section shows how both of these features are naturally accommodated by a two-sector model with distribution services.[66] Finally, counterfactual simulations based on an estimated version of the extended model also constitute a robustness check for the papers main result (see Online Appendix 4.A.3).

To keep the model description short, it focuses on the H region where possible. F equations are analogs to the H ones, and foreign variables are denoted by an asterisk. Small letters denote real variables, defined as $x = X/P$ and $x^* = X^*/P^*$.

The extension mainly affects the households' decision regarding the allocation of expenses on different consumption bundles, as well as the price dynamics and the market clearing conditions. The H-households' consumption c_t consists of non-tradable goods and retail tradable goods. The retail tradable goods themselves are composed of wholesale tradable goods and non-tradable services – e.g. local retail services. Here, for simplicity, we model the final goods directly as a CES composite of wholesale tradable goods $c_{T,t}$ and non-tradable goods $c_{N,t}$: $c_t = \left[\tilde{\gamma}^{\frac{1}{\tilde{\lambda}}} c_{T,t}^{\frac{\tilde{\lambda}-1}{\tilde{\lambda}}} + (1-\tilde{\gamma})^{\frac{1}{\tilde{\lambda}}} c_{N,t}^{\frac{\tilde{\lambda}-1}{\tilde{\lambda}}}\right]^{\frac{\tilde{\lambda}}{\tilde{\lambda}-1}}$. $\tilde{\lambda}$ is the elasticity of substitution between tradable and non-tradable goods, and $\tilde{\gamma}$ reflects the households' relative preference.

The tradable goods bundle itself is a CES bundle of home produced goods $c_{H,t}$ and imported goods $c_{F,t}$: $c_{T,t} = \left[\tilde{\alpha}^{\frac{1}{\tilde{\epsilon}}} c_{H,t}^{\frac{\tilde{\epsilon}-1}{\tilde{\epsilon}}} + (1-\tilde{\alpha})^{\frac{1}{\tilde{\epsilon}}} c_{F,t}^{\frac{\tilde{\epsilon}-1}{\tilde{\epsilon}}}\right]^{\frac{\tilde{\epsilon}}{\tilde{\epsilon}-1}}$. $\tilde{\epsilon}$ denotes the elasticity of substitution between domestic and foreign goods. If $\tilde{\alpha} > n$, the household exhibits home bias.

H produced wholesale tradable goods are a combination of H produced tradable inputs $I_{H,t}$ and H produced non-tradable inputs $V_{H,t}$: $c_{H,t} = \left[\tilde{\phi}^{\frac{1}{\tilde{\psi}}} I_{H,t}^{\frac{\tilde{\psi}-1}{\tilde{\psi}}} + (1-\tilde{\phi})^{\frac{1}{\tilde{\psi}}} V_{H,t}^{\frac{\tilde{\psi}-1}{\tilde{\psi}}}\right]^{\frac{\tilde{\psi}}{\tilde{\psi}-1}}$ with $\tilde{\phi}$ denoting the weight of tradable inputs, and $\tilde{\psi}$ denoting the elasticity of substitution between tradable and non-tradable inputs. To illustrate, locally sold agricultural goods are composed of the agricultural product itsself (e.g. grain) and local services (e.g. utility and financial services).

The home consumption of imported goods is defined as $c_{F,t} = \left[\check{\phi}^{\frac{1}{\tilde{\psi}^\star}} I_{F,t}^{\frac{\tilde{\psi}^\star-1}{\tilde{\psi}^\star}} + (1-\check{\phi})^{\frac{1}{\tilde{\psi}^\star}} V_{F,t}^{\frac{\tilde{\psi}^\star-1}{\tilde{\psi}^\star}}\right]^{\frac{\tilde{\psi}^\star}{\tilde{\psi}^\star-1}}$, with $\check{\phi} \leq \tilde{\phi}$ reflecting that imported goods require more distribution services already in the region of origin. For example, selling one ton of grain locally involves less services than selling the same ton of grain overseas, because selling overseas requires finding overseas buyers through export companies, as well as more transportation services.

The tradable goods and non-tradable goods themselves are bundles of differentiated goods that are produced by the n home- and $1-n$ foreign firms: $I_{H,t} = \left(\left(\frac{1}{n}\right)^{\frac{1}{\mu}} \int_0^n I_{H,t}(j)^{\frac{\mu-1}{\mu}} \mathrm{d}j\right)^{\frac{\mu}{\mu-1}}$, $I_{F,t} =$

[66]The extension is an adapted version of the model developed in Berka, Devereux and Engel (forthcoming).

$\left(\left(\frac{1}{1-n}\right)^{\frac{1}{\mu}} \int_n^1 I_{F,t}(j)^{\frac{\mu-1}{\mu}} \,\mathrm{d}\, j\right)^{\frac{\mu}{\mu-1}}$, $V_{H,t} = \left(\left(\frac{1}{n}\right)^{\frac{1}{\mu}} \int_0^n V_{H,t}(j)^{\frac{\mu-1}{\mu}} \,\mathrm{d}\, j\right)^{\frac{\mu}{\mu-1}}$, $V_{F,t} = \left(\left(\frac{1}{1-n}\right)^{\frac{1}{\mu}} \int_n^1 V_{F,t}(j)^{\frac{\mu-1}{\mu}} \,\mathrm{d}\, j\right)^{\frac{\mu}{\mu-1}}$, where j is the firm index and μ is the elasticity of substitution between goods produced in the same region. Direct consumption of non-tradable goods is defined in the same way: $c_{N,t} = \left(\left(\frac{1}{n}\right)^{\frac{1}{\mu}} \int_0^n c_{N,t}(j)^{\frac{\mu-1}{\mu}} \,\mathrm{d}\, j\right)^{\frac{\mu}{\mu-1}}$, $c_{N,t} = \left(\left(\frac{1}{1-n}\right)^{\frac{1}{\mu}} \int_n^1 c_{N,t}(j)^{\frac{\mu-1}{\mu}} \,\mathrm{d}\, j\right)^{\frac{\mu}{\mu-1}}$.

The H consumer price index is then given by $P_t = \left[\tilde{\gamma} P_{T,t}^{1-\tilde{\lambda}} + (1-\tilde{\gamma}) P_{N,t}^{1-\tilde{\lambda}}\right]^{\frac{1}{1-\tilde{\lambda}}}$. $P_{T,t}$ is the local wholesale price of tradable consumption goods $c_{T,t}$: $P_{T,t} = \left[\tilde{\alpha} \tilde{P}_{H,t}^{1-\tilde{\epsilon}} + (1-\tilde{\alpha}) \tilde{P}_{F,t}^{1-\tilde{\epsilon}}\right]^{\frac{1}{1-\tilde{\epsilon}}}$, where $\tilde{P}_{H,t}$ and $\tilde{P}_{F,t}$ are the prices for H-produced and imported goods, inclusive of prices for the tradable inputs $P_{H,t}$, $P_{F,t}^*$, as well as the prices for the non-tradable inputs $P_{N,t}$, $P_{N,t}^*$.

We have $\tilde{P}_{H,t} = \left[\tilde{\phi} P_{H,t}^{1-\tilde{\psi}} + (1-\tilde{\phi}) P_{N,t}^{1-\tilde{\psi}}\right]^{\frac{1}{1-\tilde{\psi}}}$ and $\tilde{P}_{F,t} = \left[\check{\phi} (P_{F,t}^*/e_t)^{1-\tilde{\psi}} + (1-\check{\phi}) (P_{N,t}^*/e_t)^{1-\tilde{\psi}}\right]^{\frac{1}{1-\tilde{\psi}}}$. The prices for the H- and F-produced goods bundles are $P_{H,t} = \left[\frac{1}{n} \int_0^n P_{H,t}(j)^{1-\mu} \,\mathrm{d}\, j\right]^{\frac{1}{1-\mu}}$ and $P_{F,t}^* = \left[\frac{1}{1-n} \int_n^1 P_{F,t}^*(j)^{1-\mu} \,\mathrm{d}\, j\right]^{\frac{1}{1-\mu}}$ respectively. The prices of H- and F-produced non-tradable goods are $P_{N,t} = \left[\frac{1}{n} \int_0^n P_{N,t}(j)^{1-\mu} \,\mathrm{d}\, j\right]^{\frac{1}{1-\mu}}$ and $P_{N,t}^* = \left[\frac{1}{1-n} \int_n^1 P_{N,t}^*(j)^{1-\mu} \,\mathrm{d}\, j\right]^{\frac{1}{1-\mu}}$. It is worth pointing out that the law of one price does not hold due to distribution service costs.

On the production side, firms' optimization problem is only slightly affected by the extension. It is assumed that there exist sector-specific technology shocks – A_t for the tradable sector and $A_{N,t}$ for the non-tradable sector. Depending on whether the firm is operating in the tradable goods or the non-tradable goods sector, it has the chance to reset its price with probability $(1-\theta_T)$ or $(1-\theta_N)$. When it can change prices, it optimizes over $P_{H,t}(j)$ or $P_{N,t}(j)$ while taking into account its demand schedule and production function. Thus, firm j's optimization problem in the tradable sector is

$$\max_{P_{H,t}(j)} \quad \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ (\beta\theta_T)^k \, \frac{\lambda_{t+k}}{\lambda_t} \frac{P_t}{P_{t+k}} \left[P_{H,t}(j) y_{T,t+k}(j) - w_{t+k} P_{t+k} l_{T,t+k}(j) \right] \right\} \tag{4.A.93}$$

$$\text{s.t. } y_{T,t+k}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t+k}}\right)^{-\mu} y_{T,t+k} \tag{4.A.94}$$

$$y_{T,t+k}(j) = A_{t+k} l_{T,t+k}^{\gamma}(j) \tag{4.A.95}$$

where l_T and y_T denote H primary sector employment and average output. The resulting first order conditions and price dynamics are very similar to those of the model without the sectoral structure. The optimization of a firm in the non-tradable sector is analogous.

The labor market clearing conditions now include the labor employed in the tradable and the non-tradable sector:

$$\Delta_{T,t}^P \, n \, y_{T,t}^{\frac{1}{\gamma}} = l_{T,t} \, n_t \, A_t^{\frac{1}{\gamma}} \tag{4.A.96}$$

$$\Delta_{N,t}^P \, n \, y_{N,t}^{\frac{1}{\gamma}} = l_{N,t} \, n_t \, A_{N,t}^{\frac{1}{\gamma}} \tag{4.A.97}$$

$$l_t = l_{T,t} + l_{N,t}, \tag{4.A.98}$$

with the measures for price dispersion $\Delta^P_{T,t} = \frac{1}{n}\int_0^n \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{\frac{-\mu}{\gamma}} dj$ and $\Delta^P_{N,t} = \frac{1}{n}\int_0^n \left(\frac{P_{N,t}(j)}{P_{N,t}}\right)^{\frac{-\mu}{\gamma}} dj$.

The goods market clearing conditions take into account tradable and non-tradable goods:

$$n\, y_{T,t}(j) = n_t\, I_{H,t}(j) + (1-n_t) I^*_{H,t}(j) \tag{4.A.99}$$

$$n\, y_{N,t}(j) = n_t\, c_{N,t}(j) + n_t\, V_{H,t}(j) + (1-n_t) V^*_{H,t}(j) \tag{4.A.100}$$

$$(1-n)\, y^*_{T,t}(j) = n_t\, I_{F,t}(j) + (1-n_t) I^*_{F,t}(j) \tag{4.A.101}$$

$$(1-n)\, y^*_{N,t}(j) = (1-n_t)\, c^*_{N,t}(j) + (1-n_t) V^*_{F,t}(j) + n_t\, V_{F,t}(j) \tag{4.A.102}$$

Finally, real output y_t is defined as the weighted average of tradable and non-tradable sector output: $y_t = \frac{P_{H,t}}{P_t} y_{T,t} + \frac{P_{N,t}}{P_t} y_{N,t}$. This average output enters the monetary policy reaction functions, as well as the money demand equations.

Terms of trade and local prices

Section 4.7.2 in the main text describes the price movements that accompanied external adjustment under the GS. The following uses the extended model to discuss the substitution effects that each of these price movements gives rise to. The terms of trade in the extended model measures the ratio of export prices to import prices at the port. The log-linearized terms of trade is

$$\widehat{ToT}_t = \hat{\tilde{P}}^\star_{H,t} - \hat{\tilde{P}}_{F,t}.$$

The CPI in the extended model can also be written as follows (see equation 4.5 in the main text):

$$\hat{P}_t = (1-\check{\gamma})\hat{P}_{N,t} + \check{\gamma}\left[\check{\alpha}\hat{\tilde{P}}_{H,t} + (1-\check{\alpha})\hat{\tilde{P}}_{F,t}\right],$$

with $\check{\gamma} \equiv \tilde{\gamma}\left(\frac{P_T}{P}\right)^{1-\tilde{\lambda}}$ and $\check{\alpha} \equiv \tilde{\alpha}\left(\frac{\tilde{P}_H}{P_T}\right)^{1-\tilde{\epsilon}}$.

How do the different price components that define the terms of trade and the CPI affect real imports and real exports? From the model, we have the following demand schedules that describe how prices affect H-households' and F-households' demand for imported goods:

$$c_{F,t} = (1-\tilde{\alpha})\left(\frac{\tilde{P}_{F,t}}{P_{T,t}}\right)^{-\tilde{\epsilon}} c_{T,t}, \quad c^\star_{H,t} = (1-\tilde{\alpha}^\star)\left(\frac{\tilde{P}^\star_{H,t}}{P^\star_{T,t}}\right)^{-\tilde{\epsilon}^\star} c^\star_{T,t}.$$

Using these demand schedules, we can write the log-linearized real imports to H ($IM_t = c_{F,t} n_t$) as

$$\begin{aligned}\widehat{IM}_t &= \hat{c}_{T,t} + \hat{n}_t - \tilde{\epsilon}\left(\hat{\tilde{P}}_{F,t} - \hat{P}_{T,t}\right) \\ &= \hat{c}_{T,t} + \hat{n}_t - \tilde{\epsilon}\tilde{\alpha}\left(\frac{\tilde{P}_H}{P_T}\right)^{1-\tilde{\epsilon}}\left(\hat{\tilde{P}}_{F,t} - \hat{\tilde{P}}_{H,t}\right),\end{aligned}$$

where the second line makes use of the relation $\hat{P}_{T,t} = \tilde{\alpha}\left(\frac{\tilde{P}_H}{P_T}\right)^{1-\tilde{\epsilon}}\hat{\tilde{P}}_{H,t} + (1-\tilde{\alpha})\left(\frac{\tilde{P}_F}{P_T}\right)^{1-\tilde{\epsilon}}\hat{\tilde{P}}_{F,t}$, as well as the steady state definition of P_T. The equation demonstrates that a unit drop in the import price ($\hat{\tilde{P}}_{F,t}$) is associated with an increase in imports of $\tilde{\epsilon}\tilde{\alpha}\left(\frac{\tilde{P}_H}{P_T}\right)^{1-\tilde{\epsilon}}$. Furthermore, a unit increase in the local price of tradable goods ($\hat{\tilde{P}}_{H,t}$) would have exactly the opposite effect on imports. As discussed in section 7.2, during major external adjustments, the local price of tradable goods falls by more than the import price. This implies a net reduction in H-imports.

Real H-exports ($EX_t = c^{\star}_{H,t} n^{\star}_t$) in log-linearized form can be written as

$$\begin{aligned}\widehat{EX}_t &= \hat{c}^{\star}_{T,t} + \hat{n}^{\star}_t - \tilde{\epsilon}^{\star}\left(\hat{\tilde{P}}^{\star}_{H,t} - \hat{P}^{\star}_{T,t}\right) \\ &= \hat{c}^{\star}_{T,t} + \hat{n}^{\star}_t - \tilde{\epsilon}^{\star}\tilde{\alpha}^{\star}\left(\frac{\tilde{P}^{\star}_F}{P^{\star}_T}\right)^{1-\tilde{\epsilon}^{\star}}\left(\hat{\tilde{P}}^{\star}_{H,t} - \hat{\tilde{P}}^{\star}_{F,t}\right),\end{aligned}$$

where the second line makes use of the relation $\hat{P}^{\star}_{T,t} = \tilde{\alpha}^{\star}\left(\frac{\tilde{P}^{\star}_F}{P^{\star}_T}\right)^{1-\tilde{\epsilon}^{\star}}\hat{\tilde{P}}^{\star}_{F,t} + (1-\tilde{\alpha}^{\star})\left(\frac{\tilde{P}^{\star}_H}{P^{\star}_T}\right)^{1-\tilde{\epsilon}^{\star}}\hat{\tilde{P}}^{\star}_{H,t}$, as well as the steady state definition of $P^{\star}_T$. A one unit decrease in the H-export price ($\hat{\tilde{P}}^{\star}_{H,t}$) leads to an increase in the foreign demand for H-produced tradable goods of $\tilde{\epsilon}^{\star}\tilde{\alpha}^{\star}\left(\frac{\tilde{P}^{\star}_F}{P^{\star}_T}\right)^{1-\tilde{\epsilon}^{\star}}$.

For an equal fall in H-import prices ($\hat{\tilde{P}}_{F,t}$) and H-export prices ($\hat{\tilde{P}}^{\star}_{H,t}$), the increase in exports will exceed the increase in imports. The reason for this is that the H-region is smaller than the F-region ($n < 1 - n \equiv n^{\star}$). Absent home bias (i.e. $n = \tilde{\alpha}$ and $n^{\star} = \tilde{\alpha}^{\star}$), this implies that a fall in export prices increases exports by more than an equivalent fall in import prices increases imports. This remains the case for all realistic degrees of home bias.[67]

Sectoral structure and external adjustment: model vs. data

Here, in order to show that the extended model naturally accommodates features of external adjustment under the GS, we compare simulated moments to the data. For the most part, the extended model is calibrated according to the baseline model estimation for the U.K. (see Table 4.1, Table 4.5.5 and Table 4.5.5).

The extended model's additional parameters are calibrated as follows: The shares of tradable goods in final consumption ($\tilde{\gamma}, \tilde{\gamma}^{\star}$) are calibrated to target the U.K.'s share of tradable value added relative to total value added (47%), and the sample average of tradable value added relative to total value added (40%). For this we rely on the sectoral share data provided by Buera and Kaboski (2012), defining services as non-tradable and all other sectors as tradable. The weights of domestically produced goods in tradable goods ($\tilde{\alpha}, \tilde{\alpha}^{\star}$) are calibrated to target the U.K. import-to-GDP and export-to-GDP ratios, as in the baseline model calibration. According to input-output tables the share of non-tradable inputs in tradable goods ($1 - \tilde{\phi}$) was around 10% during the GS era. More specifically, based on the Swedish input-output table for 1913 (Bohlin, 2007), non-tradable inputs to the tradable sector amounted to 5.4% of the total tradable sector's output. The corresponding number for the U.K., as calculated from the British input-output table for 1907 (Meyer, 1955), is higher, at 11.3%.[68] Thus, a value of 10% for $1 - \tilde{\phi}$ is of the right order of magnitude. For export goods, $\check{\phi}$ is chosen to reflect a 40% transportation cost, which implies that the export good consists of 60% tradable wholesale goods.[69]

[67] Only extreme degrees of home bias in the H region, and an extreme preference of the F region for H goods can overturn this.

[68] As $\tilde{\phi}$ reflects the non-tradable input in a wholesale product, we would ideally distinguish retail distribution services from other non-tradable inputs. However, the historical input-output tables for Sweden and the U.K. do not provide this degree of granularity.

[69] This is in line with origin-destination spreads for agricultural produce (Wilson and Dahl, 2011). For example, the price spread between corn prices in Minneapolis (the origin region) and corn prices in Georgia or the Pacific North West (ports for export) lies in the 12 to 25% range (Yu et al., 2006). On

Concerning the intra-temporal elasticity, we follow Berka, Devereux and Engel (forthcoming) in assuming an elasticity of substitution between tradable goods and non-tradable goods of 0.7 ($\tilde{\lambda} = \tilde{\lambda}^\star = 0.7$), an elasticity of substitution between tradable goods and services of 0.25 ($\tilde{\psi} = \tilde{\psi}^\star = 0.25$), and a trade elasticity of 8 ($\tilde{\epsilon} = \tilde{\epsilon}^\star = 8$).[70]

The introduction of a sectoral structure also results in four Phillips curves, that determine the price evolution of $P_{H,t}$, $P_{N,t}$, $P^\star_{H,t}$, and $P^\star_{N,t}$. To reflect the price rigidity in the non-tradable sector, we set the Phillips curve slopes for the non-tradable goods $\widetilde{\kappa}_N$, and $\widetilde{\kappa}^*_N$ to 0.05. This value corresponds to an average price duration of around 4.5 quarters, which is within the range of price rigidity estimates for advanced economies today. The Phillips curve slopes for the tradable goods are set to target a weighted average Phillip curve slope (weighted according to value-added sector shares), which equals the aggregate Phillips curve slope of 0.35 in the baseline estimation. This results in $\widetilde{\kappa}_T = \widetilde{\kappa}^*_T = 0.65$.

The simulation results are presented in Table 4.9. As in the data, increases in the CA/GDP ratio in the model are associated with an increase in tradable sector size and a decrease in non-tradable sector size (Table 4.9 panel A). The sectoral prices in the model also behave similarly to the data: the tradable prices drop during external adjustments while non-tradable prices stay more stable (panel B). The model is able to generate a relatively stable terms of trade and a larger fall in the CPI when the CA/GDP ratio increases (panel C). Finally, the model matches the observed correlation between export and import prices (panel D).

top of this, international overseas transport under the GS drove another 10 to 20% wedge between origin and destination port prices (see Persson, 2004).

[70] The higher elasticity estimates obtained from industry- and product-level data are more relevant for the two-sector model, whereas the lower trade elasticity estimates obtained from aggregate trade data are more in line with the single good baseline model (see Bas, Mayer and Thoenig, 2017).

Table 4.9: *Correlation between external adjustments, sectoral size and prices*

	Δ CA / GDP	
	Model	Data
Panel A: Sectoral sizes		
ΔTradable sector share	0.49	0.11
Δ Non-tradable sector share	-0.49	-0.08
Panel B: Sectoral prices		
Δ Tradable prices	-0.36	-0.22
Δ Non-tradable prices	0.16	-0.05
Panel C: ToT and CPI		
Δ Terms of trade	-0.11	0.07
Δ CPI	-0.21	-0.15
Panel D: Export and import prices		
	Δ Export prices	
Δ Import prices	0.52	0.59

Notes: The model moments are calculated on the basis of 2000 34-year simulations of the extended model. For more details on the stochastic simulation, see Section 4.6. Non-tradable sector share was approximated by tertiary sector share. Tradable sector share was approximated by primary sector share. Tradable prices were approximated by agricultural and raw material prices. Non-tradable prices were approximated by service sector prices.

4.A.3. Data appendix

An annual macrodataset on 14 Gold Standard economies, 1870-1913

Australia: Nominal GDP: Mitchell (2013). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Mitchell (2013). nominal USD-exchange rate: Obstfeld and Taylor (2003). Immigration & emigration: Ferenczi (1929). Population: Mitchell (2013). Narrow and broad cover ratio: Jones and Obstfeld (2004) (gold) and Mitchell (2013) (notes and deposits). Notes in circulation: Mitchell (2013). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Mitchell (2013). Agricultural, raw material and industrial exports: Coghlan (1901) (1880-1898), Statistical abstract for the several British colonies, possessions, and protectorates (1899-1900) and Official year book of the Commonwealth of Australia (1901-1912). Agricultural, raw material, industrial and service prices: Butlin (1962). Terms of trade: Wilson (1931). Export prices: Wilson (1931).

Belgium: Nominal GDP: Smits, Woltjer and Ma (2009). Real per capita GDP: Barro and Ursúa (2010). CPI: National Bank of Belgium Services Statistiques Financières et Économiques (2012), Table: Indice des prix à la Consommation en Belgique. Current account: exports - imports. Exports & imports: Mitchell (2013). Nominal USD-exchange rate: Schneider et al. (1991) (1870-1880) and Obstfeld and Taylor (2003) (1881-1913). Immigration & emigration: Mitchell (2013). Population: Annuaire statistique de la Belgique. Central bank discount rate: National Bank of Belgium (1870-1879) and Flandreau and Zumer (2004) (1880-1913). Narrow and broad cover ratio: Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925). Notes in circulation: Mitchell (2013). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Mitchell (2013). Agricultural, raw material and industrial exports: Annuaire statistique de la Belgique. Agricultural, raw material, industrial and service prices: Smits, Woltjer and Ma (2009) and Global prices and incomes database (raw materials). Terms of trade: Horlings (1998).

Canada: Nominal GDP: Jones and Obstfeld (2004). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Mitchell (2013). Nominal USD-exchange rate: Schneider et al. (1991) (1870-1899 & 1909-1913) and Obstfeld and Taylor (2003) (1900-1908). Immigration & emigration: Urquhart and Buckley (1965) & Viner (1924). Population: Maddison-Project (2013). Narrow and broad cover ratio: Leacy, Urquhart and Buckley (1983). Notes in circulation: Mitchell (2013). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Urquhart and Buckley (1965) Historical Statistics of

Canada (1881) & Mitchell (2013) (1891-1911). Agricultural, raw material and industrial exports: Statistical yearbook of Canada (1870-1904) and Canada yearbook (1905-1913). Agricultural, raw material, industrial and service prices: Urquhart and Buckley (1965) Historical Statistics of Canada. Terms of trade: Urquhart and Buckley (1965) Historical Statistics of Canada. Export prices: Urquhart and Buckley (1965) Historical Statistics of Canada.

Denmark: Nominal GDP: Mitchell (2013). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Mitchell (2013). Nominal USD-exchange rate: Denzel (2010) (1870-1880), Obstfeld and Taylor (2003) (1881-1912) and Officer (2015) (1913). Emigration: Mitchell (2013). Population: Maddison-Project (2013). Central bank discount rate: Johansen (1985) (1870-1874) and Abildgren (2005) (1875-1913) . Narrow and broad cover ratio: Johansen (1985). Notes in circulation: Johansen (1985). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Henriksen (2009). Agricultural, raw material and industrial exports: Henriksen (2009) (1874-1883), Statistical abstract for the principal and other foreign countries. (1884-1912) and Statistisk årbog (1913). Agricultural, raw material, industrial and service prices: Hansen (1974). Terms of trade: Johansen (1985). Export prices: Johansen (1985).

Finland: Nominal GDP: Hjerppe (1989). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Mitchell (2013). Nominal USD-exchange rate: Autio (1992) (1870-1880) and Obstfeld and Taylor (2003) (1881-1913). Immigration & emigration: Ferenczi (1929). Population: Maddison-Project (2013). Central bank discount rate: Autio (1996). Narrow and broad cover ratio: Ikonen (1998). Notes in circulation: Mitchell (2013). Primary, secondary and tertiary sector shares (value added): Hjerppe (1989). Agricultural labor share: Hjerppe (1989). Agricultural, raw material and industrial exports: Hjerppe (1989) (1875-1880) and Statistical yearbook of Finland (1877 & 1882-1913). Agricultural, raw material, industrial and service prices: Smits, Woltjer and Ma (2009). Terms of trade: Hjerppe (1989). Export prices: Hjerppe (1989).

France: Nominal GDP: Mitchell (2013). Real per capita GDP: Barro and Ursúa (2010). CPI: Piketty and Zucman (2014). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Mitchell (2013). Nominal USD-exchange rate: Denzel (2010) (1870-1880), Obstfeld and Taylor (2003) (1881-1912) and Officer (2015) (1913). Emigration: Mitchell (2013) (1870-1890) and Ferenczi (1929) (1891-1913). Population: Maddison-Project (2013). Central bank discount rate: De Jong (1967) (1870-1879) and Flandreau and Zumer (2004) (1880-1913). Narrow and broad cover ratio: Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925). Notes in circulation: Mitchell (2013). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Mitchell (2013), CEPII series longues macroeconomiques. Agricultural, raw material and industrial exports: Statistical abstract for the principal and other foreign countries. Agricultural, raw material, industrial and service prices: Brandau (1936) (agricultural & raw material) and Smits, Woltjer and Ma (2009) (industrial and service). Terms of trade: White (1933). Export prices: White (1933).

Germany: Nominal GDP: Burhop and Wolff (2005). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Sensch (2009) (1872-1879) and Mitchell (2013) (1880-1913). Nominal USD-exchange rate: Denzel (2010) (1870-1886) and Statistisches Jahrbuch für das Deutsche Reich (various issues). Emigration: Mitchell (2013). Population: Mitchell (2013). Central bank discount rate: Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925) (1870-1879) and Flandreau and Zumer (2004) (1880-1913). Narrow and broad cover ratio: Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925). Notes in circulation: Mitchell (2013). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Broadberry (2009) (1871 & 1913) and Mitchell (2013) (1882-1907). Agricultural, raw material and industrial exports: Sensch (2009). Agricultural, raw material, industrial and service prices: Hoffmann (1965) and Müssig (1919) (raw material). Terms of trade: Desai (2005). Export prices: Desai (2005).

Netherlands: Nominal GDP: Smits, Horlings and van Zanden (2000). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Smits, Horlings and van Zanden (2000). Exports & imports: Mitchell (2013). Nominal USD-exchange rate: Obstfeld and Taylor (2003). Immigration & emigration: Mitchell (2013). Population: Bie and Smits (2001). Central bank discount rate: De Jong (1967) (1870-1875), Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925) (1876-1879) and Flandreau and Zumer (2004) (1880-1913). Narrow cover ratio: De Jong (1967) (1870-1875) and Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925) (1876-1913). Broad cover ratio: De Jong (1967). Notes in circulation: De Jong (1967). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Van Zanden, J.L., National Accounts of the Netherlands, 1800-1913. Agricultural, raw material and industrial exports: Statistical abstract for the principal and other foreign countries. Agricultural, raw material, industrial and service prices: Van Zanden, J.L., National Accounts of the Netherlands, 1800-1913 and Van Riel (2000). Terms of trade: Bie and Smits (2001). Export prices: Bie and Smits (2001).

New Zealand: Nominal GDP: Obstfeld and Taylor (2003). Real per capita GDP: Barro and Ursúa (2010). CPI: Thorns and Sedgwick (1997). Current account: exports - imports. Exports

& imports: Mitchell (2013). Nominal USD-exchange rate: Officer (2015) (GBP-USD exchange rate). Immigration & emigration: Ferenczi (1929). Population: Maddison-Project (2013). Notes in circulation: Mitchell (2013). Agricultural labor share: New Zealand Censuses (various issues 1871-1916). Agricultural, raw material and industrial exports: Statistics of the colony of New Zealand (1875-1907) and The New Zealand official yearbook (1908-1913). Agricultural, raw material, industrial and service prices: Arnold (1982) (agricultural) and McIlraith (1911) (raw material). Terms of trade: McIlraith (1911). Export prices: McIlraith (1911).

Norway: Nominal GDP: Grytten (2004). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Mitchell (2013). Nominal USD-exchange rate: Obstfeld and Taylor (2003). Emigration: Mitchell (2013). Population: Maddison-Project (2013). Central bank discount rate: Norges Bank Historical Monetary Statistics. Narrow and broad cover ratio: Norges Bank Historical Monetary Statistics. Notes in circulation: Norges Bank Historical Monetary Statistics. Primary, secondary and tertiary sector shares (value added): Grytten (2015). Agricultural labor share: Statistisk Aarbok (various issues). Agricultural, raw material and industrial exports: Statistical abstract for the principal and other foreign countries. Agricultural, raw material, industrial and service prices: Klovland (2013) and Grytten (2015). Terms of trade: Klovland (2013). Export prices: Klovland (2013).

Sweden: Nominal GDP: Edvinsson (2004). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Schön (2015). Nominal USD-exchange rate: Denzel (2010) (1870-1880) and Obstfeld and Taylor (2003) (1881-1913). Immigration & emigration: Mitchell (2013). Population: Maddison-Project (2013). Central bank discount rate: Edvinsson, Jacobson and Waldenström (2010). Narrow and broad cover ratio: Swedish Riksbank Historical Monetary Statistics of Sweden. Notes in circulation: Swedish Riksbank Historical Monetary Statistics of Sweden. Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Schön, Krantz et al. (2012). Agricultural, raw material and industrial exports: Schön (2015). Agricultural, raw material, industrial and service prices: Swedish Historical National Accounts 1560-2010, The 2015 release. Terms of trade: Schön (2015). Export prices: Schön (2015).

Switzerland: Nominal GDP: Ritzmann-Blickenstorfer (1996). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Exports & imports: Ritzmann-Blickenstorfer (1996) (1870-1884) and Mitchell (2013) (1885-1913). Nominal USD-exchange rate: Denzel (2010) (1870-1880) and Obstfeld and Taylor (2003) (1881-1913). Emigration: Mitchell (2013). Population: Mitchell (2013). Central bank discount rate: Swiss National Bank (SNB) Historical Time Series: average of discount rates in Geneva, Basel, Zurich and St Gallen (1870-1893), Flandreau and Zumer (2004) (1894-1906) and SNB central bank discount rate (1907-1913). Narrow and broad cover ratio: SNB Historical Time Series. Notes in circulation: SNB Historical Time Series. Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Historical Statistics of Switzerland Online (1870-1880) and Mitchell (2013) (1890-1910). Agricultural, raw material and industrial exports: Statistical abstract for the principal and other foreign countries. Agricultural, raw material, industrial and service prices: Historical Statistics of Switzerland Online. Terms of trade: Historical Statistics of Switzerland Online. Export prices: Historical Statistics of Switzerland Online.

United Kingdom: Nominal GDP: Hills, Thomas and Dimsdale (2015). Real per capita GDP: Barro and Ursúa (2010). CPI: Hills, Thomas and Dimsdale (2015). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Hills, Thomas and Dimsdale (2015). Nominal USD-exchange rate: Officer (2015). Immigration & emigration: Mitchell (2013). Population: Maddison-Project (2013). Central bank discount rate: Hills, Thomas and Dimsdale (2015) (1870-1875), Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925) (1876-1879) and Flandreau and Zumer (2004) (1880-1913). Narrow and broad cover ratio: Bank of England Historical Balance Sheet. Notes in circulation: Bank of England Historical Balance Sheet. Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Mitchell (2013). Agricultural, raw material and industrial exports: Statistical abstract for the United Kingdom. Agricultural, raw material, industrial and service prices: Clark (2004) (agricultural), Layton and Crowther (1935) (raw material) and Feinstein (1972) (industrial and service). Terms of trade: Hills, Thomas and Dimsdale (2015). Export prices: Hills, Thomas and Dimsdale (2015).

United States: Nominal GDP: Johnston and Williamson (2011). Real per capita GDP: Barro and Ursúa (2010). CPI: Hills, Thomas and Dimsdale (2015). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Mitchell (2013). Immigration & emigration: Mitchell (2013) (immigration) and Ferenczi (1929) (emigration). Population: Maddison-Project (2013). Narrow and broad cover ratio: Jones and Obstfeld (2004) (gold), Federal Reserve Bank of St. Louis FRED (silver and foreign exchange), Mitchell (2013) (notes). Notes in circulation: Mitchell (2013). Primary, secondary and tertiary sector shares (value added): Buera and Kaboski (2012). Agricultural labor share: Mitchell (2013). Agricultural, raw material and industrial exports: Statistical abstract for the principal and other foreign countries (1870-1906) and Department of Commerce and Labor of Commerce and of Statistics (1907) (1907-1913). Agricultural, raw material, industrial and service prices: Historical Statistics of the United States 1789-1945 (agricultural & industrial) and Brandau (1936) (raw material). Terms of trade: Lipsey (1963). Export prices: Lipsey (1963).

Sectoral exports

Table 4.10: *Export categories*

Country	Disaggregate export component series:		
	Agricultural	Raw material	Industrial
Australia	*1880-1898*: wool, tallow, butter, live stock, meat, sugar, wheat and flour, jams, fruit, potatoes and other vegetable products. *1899-1900*: butter, flour, fodder, fruit (green), grain (oats and wheat), hay and chaff, hides, live stock (horses), cold-preserved meat (beef), mutton and lamb, rabbits and hares, meat (preserved in tins), oil (cocoanut in bulk), skins (sheep and other), sugar (cane and other), tallow, wine (fermented), wool (in the grease and scoured). *1901-1912*: animal foodstuffs etc., vegetable foodstufs etc., beverages (non-alcoholic), alcoholic liquors, tobacco, live animals, animal substances, vegetable substances.	*1880-1898*: coal, silver (lead and ore), tin, copper, hides and skins, gold, minerals, timber, sandal-wood, pearl shell, pearls, guano. *1899-1900*: bark (for tanning), coal, coke, copper (ore, ingots, bars) gold, lead (pig and matte), pearlshell, silver and silverware, silver (lead), skins (rabbit, hare and other), tin (ore and ingots), wood and timber, gold and silver buillion. *1901-1912*: oils, stones, metals (ores), wood.	*1880-1912*: apparel, paints, metals (part manufactured and manufactured), leather, earthenware, paper, jewellery, instruments, drugs
Belgium	*1870-1913*: starch, bovine, ovine, swines, horses, beers, canned cheese, other canned foods, butter, flour, bran/food/starch/moutures, grains, milk and cheese, vegetables (and potatoes), eggs, bread/sea biscuit/macaroni etc., fish, rice, meat, mixed delicacies, fruits, alcoholic drinks/liquor/brandies, animal fats, other animal products, crops and fodder, beets, hop, yeast, plants and flowers, vegetables (non-specified), wine	*1870-1913*: wood (construction and other), coffee, rubber (raw and processed), black coal, coke, salt (raw), linen and hemp rags, oils/food and other, lime, iron and steel filings, sulfur, other minerals, steel (raw and ingots), copper and nickel, iron (raw and old), gold/silver and platinum, lead, zinc, other metals, raw skins, stones (raw and finished), resin and bitumen, sugar (raw), tobacco, bark, seeds (oily), seeds (other), broken glass and cullet	*1870-1913*: arms, candles, ropes, salt refined, drugs, fertilizer, yarn (cotton, wool, goat hair, linen and silk), clothing, cars and streetcars, other machines, textiles (hemp, cotton, etoupes, jute, wool, linen, silk, other), haberdashery and ironmongery, iron (processed), furniture, watches, art objects, paper, prepared skin, processed skin, pottery, chemicals, various products for industry, typographical products, soap, sugar (refined), tinctures and colors, tissues (cotton, wool, linen, jute, hemp, silk, not specified), tulles (lace trimming and satin lace), glasswares, cars
Canada	*1870-1913*: products of fisheries, animals and produts of, agricultural product	*1870-1913*: prodcts of mines, products of forest (raw)	*1870-1913*: products of the forest (manufactured and partially manufactured), manufactures
Denmark	*1870-1873*: meat and cattle, pork and pigs, butter, other animal, cereals, flour, grains and bread, other vegetable, food, drink. *1874-1883*: agricultural exports.	*1870-1873*: hides and skins. *1884-1912*: coal, coffee (raw), coffee (roasted), oil/petroleum and other, sugar (raw and refined), tobacco, wood.	*1870-1873*: goods of iron and metal industry, texile and clothing, articles of stone/clay and glass industry, other industrial goods.

	1884-1912: horses, cattle, sheep and goats, swine, beer, butter (in hermetically sealed boxes), eggs, fish (except shell fish, fresh), fish (preserved and salted), barley, wheat, wheat flour, lard and fat, meat (incl. hams and sausages), rice flour, seeds (oleaginous and other), spirits/brandy and other, wool (raw). *1913*: living animals, animal products, cereals, fodder, garden products and fruit, beverages and spirits, diverse plant materials.	*1913*: colonial goods, skins/fur/feathers/bonse (and other animal products), tallow/oil/rubber/resin/tar, wood, minerals (raw or drafted), other metals	*1884-1912*: hides and skins (prepared and manufactured), iron and steel manufactures, wool manufactures. *1913*: textile materials, yarn, textile products, clothes, manufactures of skins/fur/feathers/bones etc., products of tallow/oil/rubber/resin/tar, wood (processed), paper, other plants-based products, chemicals and fertilizers, mineral products, ships/cars/machines and instruments.
Finland	*1875-1880*: agricultural exports. *1882-1891*: butter, meat, milk, cheese, horses, cattle, pigs, other live animal, corn (grain), corn (flour and groats), fish, poultry, fruits, yarn, hay, vegetables and horticultural products, canned food, drinks. *1892-1913*: living animals, other animal products (meat etc.), fish, starch foods, horticultural products and potatos, fruits and berries, canned shellfish, drinks, animal products (bones, horns, hair), plants/seeds/vegetable materials.	*1875-1880*: forestry, wood industry. *1882-1891*: wood, firewood, iron and steel, skins, tar pitch, cumin, willow bark, potash, colonial goods (spices and tobacco), other animal products, oils and fats, minerals (raw and products thereof), metal. *1892-1913*: colonial goods, skin and leather, pelts, wood (raw and products), resin and tar, oils and fats, minerals (raw and processed), metals.	*1875-1880*: paper, textile industry, metal and engineering industries, other manufacturing. *1882-1891*: wood pulp, paper and cardboard, leather, glassworks, wallpapers, pottery and earthenware, textiles and tissue, yarn, woodworks, candles, ships, drugs, clothes/hats/caps, cosmetics, chemicals, explosives and accelerants, colors and tinctures, machines, instruments, cars, artistic goods, luxury goods. *1892-1913*: paper and carton, spinning products yarn, tissues, clothing/hats/caps, cosmetics, chemical products, explosives and accelerants, colors and tinctures, machines, instruments, car, ships, artistic works, luxury products.
France	*1870-1913*: horses, other animals, brandy and other spirits, butter, margarine, cheese, cotton (raw), eggs, fruit (fresh and preserved), grain and flour, oil cake, sardines (preserved in oil), potatoes, other sorts of vegetables (fresh or preserved), wine, wool (raw).	*1870-1913*: hides (raw), iron/steel and manufactures of), pig iron, steel ingots/billets etc., oils (volatile and essential), rags (wollen), silk (raw, thronw, waste and cocoons), sugar (raw and refined), wood (common).	*1870-1913*:chemical products, colors and dyes (prepared), copper wire, cotton yarn, cotton manufactures (piece goods, unbleached, bleached, dyed, printed, mixed), lace and patent net, hosiery and knitted wares, trimmings, earthen and china ware, flax and hemp yarns, glass and glass wares, haberdashery/small fancy wares and toys, hides (tanned or curried), rails, other partly wrought iron, constructional iron and steel (manufactured), enamelled and tinned wares, all other manufactures, jewellery, leather wares (boots and shoes, gloves and other), machines and machinery (and parts thereof), metal wares and tools (except of iron and steel), medicines (prepared), millinery, motor cars and vehicles, paper (and manufactures thereof), perfumery and toilet soaps, silk (spun), silk and waste silk (tissues, gauze, lace and ribbons), soap, wool yarn, wool manufactures, cloths/casimirs and similar tissues, dress stuffs of pure wool, stuffs of wool mixed with other materials.
Germany	*1872-1913*: food industry exports	*1872-1913*: raw materials and semifinished products, metals	*1872-1913*: finished products

Netherlands	*1878-1889*: animals living (cattle, sheep and pigs), animals (horses), bran, butter, cheese, cotton (raw), fish (fresh, preserved, incl. salmon), flax (raw), grain and flour, wheat and wheat flour, ryea and rye flour, oats and oats flour, margarine and artificial butter, margarine (oleo), rice and rice flour, spirits (incl. liqueurs), tallow and lard, vegetables (fresh and preserved), wool (raw), yeast. *1878-1889*: articles of food and live animals.	*1878-1889*: copper (ore and unwrought), guano, hair of all sorts (unmanufactured), hides and skins (raw), indigo, iron and steel (pig iron), madder, oil (seeds), palm oil, salpetre (unrefined), spelter or zinc (unwrought), sugar, tin (unwrought), tobacco (leaf). *1878-1889*: raw materials.	*1878-1889*: candles, cotton (yarn and manufactures), drugs (Peruvian bark and other), dye stuffs, iron bars (rails etc.), iron wares (incl. nails and wire), steel and manufactres, machinery of all kinds, wool (yarn and manufactures). *1878-1889*: manufactured articles
New Zealand	*1870-1874*: wool, meat, butter, dairy, grain. *1875-1880*: wool, tallow, hides, sheepskins, rabbitskins, flour, bran and sharps, wheat, barley, malt, oats, oatmeal, potatoes, hops, butter, cheese, bacon and hams, salt beef and pork, preserved meats, frozen meat, whalebone, sealskins, whale oil (black and sperm whales), *1881-1913*: the fisheries, animals and produce, agricultural products.	*1870-1874*: timber, gum, gold *1875-1880*: gold, silver, coal, kauri gum, timber (sawn and hewn, logs, spars, laths, palings, posts and shii). *1881-1913*: the mine, the forest.	*1875-1880*: leather, cordage, phormium (New Zealand hemp), *1881-1913*: manufactures.
Norway	*1878-1900*: horses, beer, fish (fresh), cod (dried or split), herrings (salted), other salted fish, anchovies, lobster, fish roes, grain (oats), *1901-1913*: bran, butter, condensed milk, fish (fresh), cod (dried or split), herrings (salted), other salted fish, anchovies, lobster, fish roes	*1878-1900*: skins (calf), skins (seal), sulphur, train oil, wood (rough or planed, hwen, in boards, laths, etc., spars, stakes, pit props, beams and other hewn wood, split wood and firewood). *1901-1913*: copper (crude, refined, old and scrap), fish guano, hides and skins, ice, sulphur, train oil, wood (rough or planed, hewn in boards, laths, etc., spars, stakes, pit probs etc., beams and other hewn wood, staves, pit props, split wood, firewood etc., zinc (crude).	*1878-1900*: iron manufactures (nails), lucifer matches, cotton manufactures, packing paper, wood manufactures, wood pulp (mechanical process), wood pulp (chemical process). *1901-1913*: calcium carbide, iron nails, lucifer matches, paper (packing), paper (printing), sailing and steam vessels, wood pulp (mechanical and chemical process)
Sweden	*1870-1913*: agriculture and subsidiaries, food industries.	*1870-1913*: mining metal, stone and clay, wood industries, leather and rubber	*1870-1913*: paper industries, textile and clothing, chemical industries
Switzerland	*1885-1913*: articles of food	*1885-1913*: raw materials	*1885-1913*: manufactured articles
United Kingdom	*1872-1897*: animals (horses), beer and ale, biscuit and bread, butter, cheese, corn (wheat), wheat flour, corn (other kinds), fish (herring and of other sorts), pickles and vinegar sauces, provisions (not otherwise described), spirits. *1898-1913*: grain and flour, meat (incl. animals for food), other food and drink, tobacco.	*1872-1897*: clay (unmanufactured), coals (cinders and fuel), grease (tallow and animal fat), oil (seed), rags (and other materials for paper), salt, seeds of all sorts, skins and furs (British), sones and slates (slate by tale), wool (sheep and lambs, nolls, waste). *1898-1913*: coal, coke and patent fuel, iron ore, other metalic ores, wood and timber, cotton, wool (sheep and lambs; woll waste, noils) other textile materials, oil seeds nuts, oils, fats and gum	*1872-1897*: alkali, apparel and slops, arms and ammunition, bags, bleaching material, books, candels, caoutchoue manufactures, carriages and waggons railway, cement, chemical products and dye stuffs, clocks and watches, coal products, cordage and twine, cotton yarn and twist , cotton manufactures, cycles, earthen and china ware, electric lighting apparatus, furniture, cabinet and upholstery wares, glass (plate, flint, common bottles, other sorts), haberdashery and millnery

		, hides and undressed skins, materials for paper making, miscellaneous raw materials and articles mainly unmanufactured.	, hardware and cutlery, hats, implements of tools of industry, instruments and apparatus, leather, linen yarn, jute yarn, linen manufactures, jute manufactures, steam engines, other machines, medicines, metals, musical instruments, oil and floor cloth, painters' colors, paper and pasteboard, pictures, plate and plated ware, sewing machines, sild, thrown, twist and yarn, silk manufactures, skins and furs, soap, stationary other than paper, grindstones, millstones and other sorts of stones, sugar (refined), telegraphic wire, umbrella and parasols, wood and timber manufactures, wool, wollen and worsted yarn and manufactures, yarn, alpaca and mohair and other sorts unenumerated, other articles. *1898-1913*: iron and steel and manufactures thereof, other metals and manufactures thereof, cutlery, hardware implements and instruments, telegraph cables and apparatus, machinery, ships, manufactures of wood and timber, yarns and textile fabrics (cotton yarn and manufactures, wollen yarn and manufactures, other materials), apparel, chemicals, drugs, dyes and colors, leathers and manufactures thereof, earhware and glass, papers, miscellaneous articles wholly or mainly manfactured
USA	*1870-1912*: foodstuffs in crude condition and food animals, foodstuffs partly or wholly prepared.	*1870-1912*: crude materials for use in manufactures.	*1870-1912*: manufactures for further use in manufactures, manufactures ready for consumption.

How much of international trade does our 14 country gold block sample cover? To answer this question we calculated within Gold Standard trade shares:

$$impshare_{i,t} = \frac{\sum_{j \in gold} imp_{ij,t}}{imp_{i,t}} \quad \text{and} \quad expshare_{i,t} = \frac{\sum_{j \in gold} exp_{ij,t}}{exp_{i,t}},$$

where i is the country index and t the time index.[71]

The average import and export shares are listed in Table 4.11. 75% of imports come from other GS members in the sample, while 84% of exports go to other GS members in the sample. There is some variance over time and across countries, but even the smallest import share is 49%, while the smallest export share is 57%.

These numbers point towards the gold block being a fairly self-contained trading block. While some important trading partners were not members of this gold block (e.g. India, China, Argentina or Brazil), the data clearly indicate that such trade usually did not amount to more

[71] We use bilateral trade flow data provided by Barbieri, Keshk and Pollins (2008), Jacks, O'Rourke and Williamson (2011) and Mitchell (2013).

Table 4.11: *Within Gold Standard trade shares*

	Mean	SD	Min	Max	N
Import share	0.75	0.14	0.49	1.00	440
Export share	0.84	0.11	0.57	1.00	440

Notes: Average within gold-block trade shares (14 countries from the baseline sample). Different denominators for the calculation of the trade share: aggregate trade measure (e.g. $\sum_{j\in gold} imp_{ij}/imp_i$), sum of bilateral trade measures (e.g. $\sum_{j\in gold} imp_{ij}/\sum_j imp_{ij}$) and the same measures calculated on the basis of interpolated trade measures.

than one quarter of trade for the gold block countries.[72]

Migration data

One important source for migration numbers are port statistics, which have been introduced in most early developing countries after the Napoleonic wars.[73] These port statistics provide information about departures and arrivals. Another important source are communal registers that noted changes in place of residence or naturalizations.

Generally, receiving countries tended to focus on collecting immigration data, while sending countries focused on collecting emigration data. Thus, for sending countries, there do not always exist immigration data (e.g. Denmark, Germany or Norway). Similarly, for receiving countries emigration data tends to be less readily available than immigration data. For example, our emigration series for Canada only starts in 1900.

Immigration data for receiving countries (Australia, Canada, New Zealand, USA) is usually considered to be of high quality. They are also more comparable than emigration statistics from European countries. Partly this is due to some European passport statistics and communal registers confounding intentions to emigrate with actual emigration. Partly this is due to port statistics only covering overseas or intercontinental migration. As long as such cross country heterogeneity in data collection only affects the migration series' level, while leaving its cyclical properties intact, all results discussed in the paper are robust, as we only analyze the series' cyclical properties.

However, there also exists the concern that the migration data do not cover temporary emigration and subsequent return migration. If this was the case fluctuations in the labor migration series would underrepresent the true extent of labor migration. For example, if good economic prospects lead to an influx of undocumented temporary workers on top of documented permanent immigrants, the migration time series would systematically underrepresent the true extent of cyclical labor movements. As a consequence, the sensitivity of

[72]Note that these within Gold Standard trade shares are about twice as large as those reported in the online appendix to Catão and Solomou (2005). This is due to Catão and Solomou (2005) including only Germany, France, the U.K. and the U.S. among the gold block countries.

[73]The following description of the migration data makes ample use of the data descriptions given in Ferenczi (1929) and Mitchell (2013).

migration flows might be underestimated, and counterfactual per capita volatilities could give an erroneous impression of the relevance of migration flows for external adjustment. For this reason Table 4.A.3 lists information about the degree of return migration where such information is available.

Table 4.12: *Migration data*

Country	Time	Type	Source	Notes
Australia	1870-1913	arrivals & departures	Ferenczi (1929)	Return migration to U.K. inconsequential in 1870s (10%), but grows in importance in the late 1880s (to about one third).
Belgium	1870-1913	arrivals & departures	Mitchell (2013)	Arrivals and departures, from and to foreign countries. Recorded in local registers of resident population. Data appear incomplete before the late 1900s.
Canada	immigration: 1870-1913 emigration: 1900-1913	immigration & emigration	Viner (1924) & Urquhart and Buckley (1965)	
Denmark	emigration: 1870-1913	controlled emigration	Mitchell (2013)	intercontinental emigration of citizens
Finland	immigration: 1894-1913 emigration: 1870-1913	immigration & emigration	Ferenczi (1929)	Intercontinental emigration of all citizens. Prior to 1881 only emigrants to U.S. series (spliced).
France	immigration: 1880-1913 emigration: 1870-1913	immigration & emigration	Ferenczi (1929), White (1933), Mitchell (2013)	French emigration statistics tend to show fewer emigrants than receiving countries' statistics show French immigrants. French emigration statistics only cover intercontinental migration; up to 1891: steerage passengers of French citizenship at le Havre, Bordeaux, Bayonne, and at various times other French ports. The immigration numbers are from White (1933), and they are based on population data and death/birth rates.
Germany	emigration: 1870-1913	emigration	Mitchell (2013)	Litte return migration from the U.S.. Intercontinental emigration of German citizens through German or major foreign ports. Almost identical migration numbers in origin and destination country.
Netherlands	1870-1913	immigration & emigration	Mitchell (2013)	Intercontinental emigration of Dutch citizens through Dutch ports.
New Zealand	1870-1913	arrivals & departures	Ferenczi (1929)	
Norway	emigration: 1870-1913	emigration	Mitchell (2013)	Intercontinental emigration of citizens; up to 1876 only emigrants to the U.S.. Norway exhibits only very little discrepancy between U.S. immigration and local emigration statistics.
Sweden	1870-1913	immigration & emigration	Mitchell (2013)	All residents moving to take up permanent residence.
Switzerland	immigration: 1891-1913 emigration: 1870-1913	immigration & emigration	Mitchell (2013)	Emigration statistics include intercontinental migration of citizens and foreign residents. Immigration statistics only cover naturalisations of foreigners. Statistics up to 1889 are known to be incomplete. Emigration statistics considered to be of high quality, as Swiss emigration numbers coincide with immigration numbers from destination countries.

United Kingdom	1870-1913	arrivals & departures	Mitchell (2013)	Up to 1876 intercontinental passengers to and from U.K. ports (incl. Irish ports). from 1876 onwards intercontinental passengers to and from U.K. ports (U.K. citizens only). Somewhat more than one third of British emigrants to the U.S. returned home.
United States	immigration: 1870-1913 emigration: 1870-1913 (gaps)	immigration & departures	Ferenczi (1929), Mitchell (2013)	Up to 1906: aliens with intent to reside. From 1906: aliens arriving with intent to settle. Arrivals in alaska are only irregularly included up to 1903. Arrivals in Hawaii and Puerto Rico are included from 1901 and 1902 on, respectively. Land frontier arrivals only regularly included from 1908 on. 1892 to 1903: First or second-class passengers were excluded. From 1904 on aliens in transit were excluded. Aliens returning from visits abroad were excluded from 1907 on. Emigration statistics only start in 1908. Before that the emigration series is based on passenger data. Years ending 30 June.

Scandinavian countries tend to see very little return migration from North America (only 10%). Similarly, there was little return migration of German emigrants to the U.S. Among British emigrants to the U.S. however somewhat more than one third returned home. Also about one third of British migrants to Australia returned by the late 1880s. Fortunately, however, the migration data for the U.K. are based on port statistics that document arrivals and departures. They thus cover the extent of return migration to the U.K.

To get an idea about how pre-1914 cyclical fluctuations in overall arrivals were related to cyclical fluctuations in immigration we looked at the one country in our sample for which we have immigration as well as arrivals data: Finland. We find that the Pearson correlation coefficient for immigration and arrivals exceeds 0.8 for first differences and 0.9 for 5-year differences. This indicates that the cyclical fluctuations in the migration data collected from different sources was highly correlated.

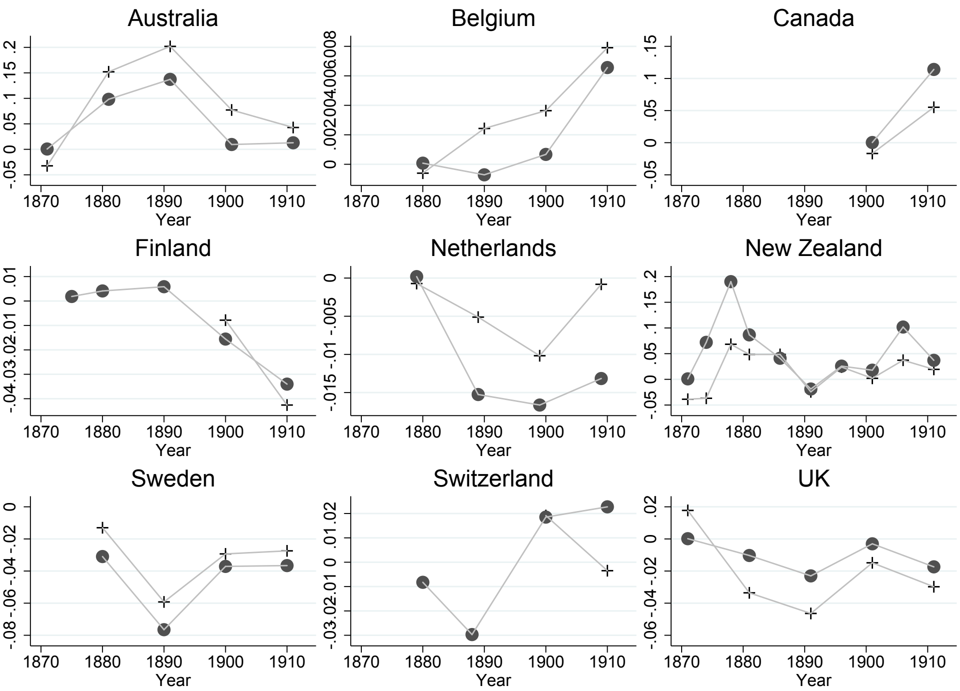
Note that for the model estimation we exclusively rely on net figures, i.e. net immigration. In principle, net immigration series possess validity in excess of the underlying gross series in that net-arrivals equal net immigration, even if the gross figures differ.[74]

One way of cross-validating the net immigration series obtained from immigration and emigration data is to see whether it is consistent with the net immigration (*netim*) implied by population data and vital statistics (death rate- and birth rate-data). Given the end of period population level (*pop*), birth rates (*BR*) and death rates (*DR*), net immigration can be calculated as:

$$netim_t = pop_t - pop_{t-1} * (1 + BR_t - DR_t).$$

[74]Only if reporting periods were straddled by important holiday or business-traveling seasons would the two differ. There is no indication that this was the case. Even if it was the case, seasonal tourism at the time was an elite phenomenon whose effect on overall population movement statistics must have been very small.

Figure 4.6: *Immigration rates: migration data vs. population and vital data*



Notes: Plus (+) signs – cumulative intercensal netimmigration/population rate, calculated from immigration and emigration data. Circles – cumulative intercensal netimmigration/population rate, calculated from the preceeding census' population data, death rates and birth rates.

To be sure, the suggested cross-validation exercise jointly tests the quality of immigration and vital statistics. However, given that for most early developing countries vital statistics by the late 19th century are of good quality, any resulting discrepancy between the two series is more likely to be attributable to the migration statistics.[75] One period in the following is the time from one population enumeration to the next. Although annual population estimates exist for this period, they are of little use for this cross-validation exercise, because they usually are estimated on the basis of birth rates, death rates and migration data. The suggested cross-validation attempt would thus become circular.[76] Most countries in our sample conducted decennial censuses in the late 19th and early 20th century, so that in the following we compare cumulative net immigration rates over ten-year periods.

For all countries for which we have sufficient immigration and emigration data, Figure 4.6 plots the two net immigration/population series – one derived from the migration statistics

[75] The same argument is provided by primary sources when explaining the discrepancy between population estimates and population enumerations. See, for example, the population statistics section of the Official yearbook of the Commonwealth of Australia from 1913.

[76] For the same reason we do not calculate a vital statistics-based net immigration series for France, because the French immigration series we use was itsself derived from vital statistics, rendering this exercise circular for the case of France (see White, 1933. The French International Accounts 1880-1913. p.77. Table 11: Funds brought into France by immigrants, 1880-1913, Immigration).

(plus symbols), and the other derived from the census population enumerations and vital statistics (circle symbols).[77] In general, the fluctuations of the two series are similar. Note that the results of all analyses presented in this paper are robust to any level differences, as our analysis is based on the series' cyclical properties only. In general, these results make us confident that the migration series are informative about the medium-term swings in international population movements, in which we are interested in.[78]

Sectoral price data

The sectoral price data come from various sources and most commonly are either wholesale price indices or implicit sectoral deflators. We never use price data from trade statistics. In this way we ensure that the sectoral price indices reflect the prices of locally produced goods.

Table 4.13: *Sectoral price data*

Country	Time	Source	Notes
Australia	1870-1913	Butlin (1962)	*agricultural*: average of pastoral, agriculture and dairying price indeces. Pastoral index contains wool and livestock prices. Agricultural wholesale price index based on nine goods. Dairying index is a weighted average of wholesale prices for butter, eggs and honey. *raw materials*: based on price of gold and coal. Gold's relative importance declines substantially after 1911, and the index tends to give too much weight to it after that year Butlin (see 1962, p.456). *industrial*: industrial price index (composed of four industrial goods' wholesale price series, and industrial wage-rates). *services*: based on prices for private water transport, government business undertakigs (railway freight rates and wage incomes), government services, property and finance, professional and domestic service, distribution.
Belgium	1870-1913	*agricultural, industrial & services*: Smits, Woltjer and Ma (2009). *raw materials*: Global prices and incomes database.	*agricultural*: implicit agricultural, hunting and forestry deflator. *raw materials*: average price of lampoil, kerosene and coal in Ghent 1816-1925. *industrial*: industry deflator. *services*: index based on prices for wholesale and retail trade, hotels and restaurants, transport, storage, communication, financial intermediation, real estate, renting and business activity, community, social and personal services.
Canada	*agricultural*: 1870-1913. *raw material & industrial*: 1890-1913. *services*: 1900-1913.	Urquhart and Buckley (1965)	*agricultural*: wholesale prices of 15 foodstuffs (from Toronto newspapers). *raw materials*: wholesale price of raw and partly manufactured goods. *industrial*: wholesale price of fully and chiefly manufactured goods. *services*: index based on prices for domestic electric light and hospital charges.

[77] For Denmark, Germany and Norway there exist no immigration series, so there exist no net immigration rates from migration data for comparison. France is excluded because its immigration series is an estimate based on vital statistics. Emigration data for the U.S. allows only for the calculation of a single net immigration rate observation. This provides no information with respect to the validity of the cyclical variations in the net immigration series.

[78] Note that for the model estimation we allow for measurement error in the net immigration series.

Denmark	1870-1913	Hansen (1974)	*agricultural*: implicit deflator for agricultural production. *raw material*: implicit deflator for forestry, peat- and lignite production. *industrial*: implicit deflator for craftsmanship, industry, etc. *services*: implicit deflator of trade etc.
Finland	1870-1913	Smits, Woltjer and Ma (2009)	*agricultural*: implicit deflator for agricultural and fishing production. *raw materials*: implicit deflators for forestry production. *industrial*: implicit deflator for manufacturing production. *services*: implicit deflator for trade, transport, storage and communications, financial intermediation, real estate, renting and business activities.
France	*agricultural & raw material*: 1871-1913. *industrial & services*: 1870-1913.	*agricultural & raw material*: Brandau (1936). *industrial & services*: Smits, Woltjer and Ma (2009).	*agricultural & raw material*: wholesale price indices. *industrial*: implicit deflator for total industry production. *services*: implicit deflator for trade, transport, real estate activities, total government, other community, social and personal service activities and private households with employed persons.
Germany	1870-1913	*agricultural, industrial & services*: Hoffmann (1965). *raw materials*: Müssig (1919).	*agricultural*: retail- and wholesale prices. *raw materials*: price index based on prices for coal, coke, spar, ore, iron. *industrial*: price index based on industrial inventory, industrial supplies, railway construction, agricultural machinery and equipment, furniture, household goods, heating, clothing, textile household goods, leather goods, health and personal care goods, cleaning goods.*services*: price index based on services of doctors and nursing staff, housing, domestic services, education, recreation, transport and public consumption.
Netherlands	1870-1913	*agricultural, industrial & services*: Van Zanden, J.L., National Accounts of the Netherlands, 1800-1913. *raw materials*: Van Riel (2000).	*agricultural, industrial & services*: sectoral deflators. *raw materials*: based on prices for copper, tin, lead, coal and peat.
New Zealand	*agricultural*: 1870-1913. *raw materials*: 1870-1910.	*agricultural*: Arnold (1982). *raw materials*: McIlraith (1911).	*agricultural*: total food consumer prices. *raw materials*: non-farm commodity price index.
Norway	1870-1913	*agricultural, raw materials & industrial*: Klovland (2005). *services*: Grytten (2015).	*agricultural*: based on prices for feeding stuffs, vegetables, grain, fish, dairy product and meat. *raw materials*: based on prices for metals, minerals and timer and wood. *industrial*: based on prices for manufactures of wood and manufactures of textiles. *services*: based on prices for commerce, transport and communication, government services, community and business services, personal services, domestic services and misc.
Sweden	1870-1913	Swedish Historical National Accounts 1560-2010, The 2015 release.	*agricultural*: based on prices of products from agriculture, forestry, hunting and fishing, horticulture sectors. *raw materials*: based on prices of products from mining and metals industry. *industrial*: based on prices of products from paper and printing industries, textile and clothing industry, leather, hair and rubber industries, chemical industries, building and construction. *services*: based on prices for foreign shipping, domestic shipping, stevedoring, timber floating, stage-post services, horse-drawn transports, railways, postal services, telecommunications, trade and commerce, private services and dwelling services

Switzerland	*agricultural, raw materials & industrial*:1870-1913. *services*: 1890-1913.	Historical Statistics of Switzerland Online	*agricultural*: price index for food and beverage: animal, vegetable and processed products. *raw materials*: price index for fuels, chemicals, metals and building materials. *industrial*: price index for textiles (cotton, silk, wool, linen), skins and leather. *services*: tertiary sector, implicit deflator.
United Kingdom	*agricultural, raw materials & industrial*: 1870-1913	*agricultural*: Clark (2004). *raw materials*: Layton and Crowther (1935). *industrial*: Maynard (1962) Tinbergen (1956)	*agricultural*: farm index; composite of arable products, meat, dairy, wool, and pasture products; index for the price of the net output of products of the agricultural sector of the economy; products used as inputs in the farm sector (e.g. animal fodder) get less weight. *raw materials*: raw material price index based on the wholesale price of 44 to 45 commodities. *industrial*: based on prices for clothing, durable household goods and other goods. *service*: based on prices for transport and communication, and other services.
USA	*agricultural, raw materials & industrial*: 1870-1913	*agricultural & industrial*: Historical Statistics of the United States 1789-1945. *raw materials*: Brandau (1936).	*agricultural*: wholesale farm product price index. *raw materials*: wholesale prices for industrial raw materials. *industrial*: wholesale prices of textile products, chemicals and drugs, house-furnishing goods. *service*: imputed with sectoral share data and GDP deflator.

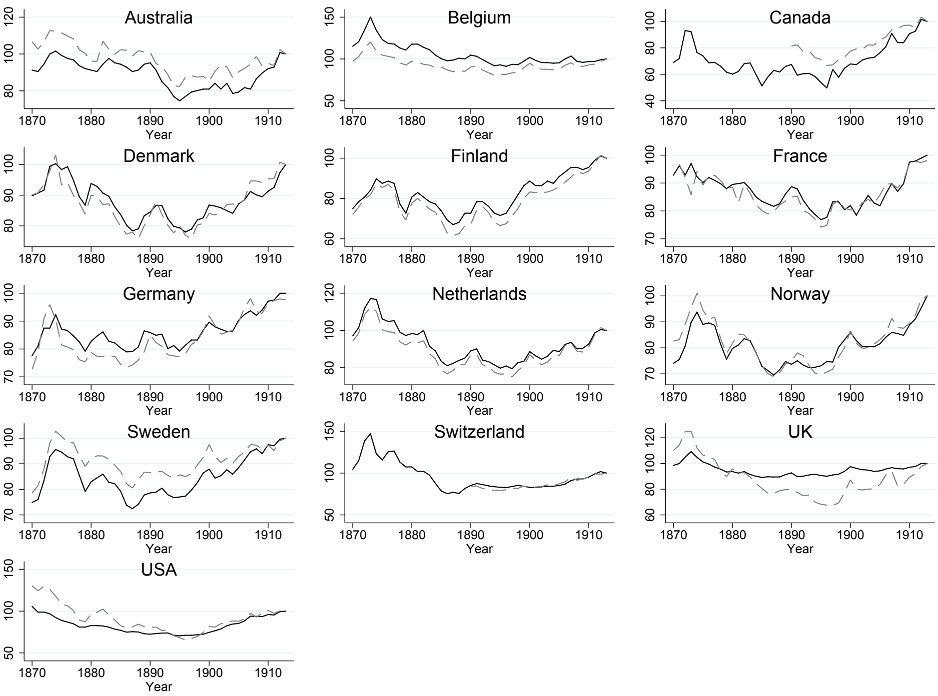
In order to assess the validity and reliability of these sectoral price series we built their weighted average and compared it to GDP deflators. In particular we look at the weighted arithmetic average, where the weights are the sector shares provided by Buera and Kaboski (2012). Because the sectoral price data distinguishes between agriculture, raw materials, industry, and services, whereas the sectoral share data by Buera and Kaboski (2012) only distinguishes between primary (agriculture), secondary (mining and industry) and tertiary (services) we aggregate the sectoral price data in the following way:

$$P_t = prim_t * P_t^{agri} + second_t * (P_t^{indu} + P_t^{raw})/2 + tert_t * P_t^{serv}.$$

When there was no service price indicator available (U.S.), or when service prices are only available for a short period of time (Canada and U.K.) we drop the third term from this equation and rebase the primary and secondary sector shares: $prim_t/(prim_t + second_t)$ and $second_t/(prim_t + second_t)$.

The resulting series for each country are shown as gray dashed lines in Figure 4.7. In almost all cases the price level estimate derived from the sectoral price data is very similar to GDP deflator series obtained from different sources. Only in the case of Canada, the U.K. and the U.S., for which service price indices are either not available, or have been dropped because they were only available for short time periods, is the match less exact. New Zealand is missing from this graph owing to a lack of sectoral share data. In general, the consistency between the sectoral price series and the much more widely used and better vetted GDP deflator series is reassuring.

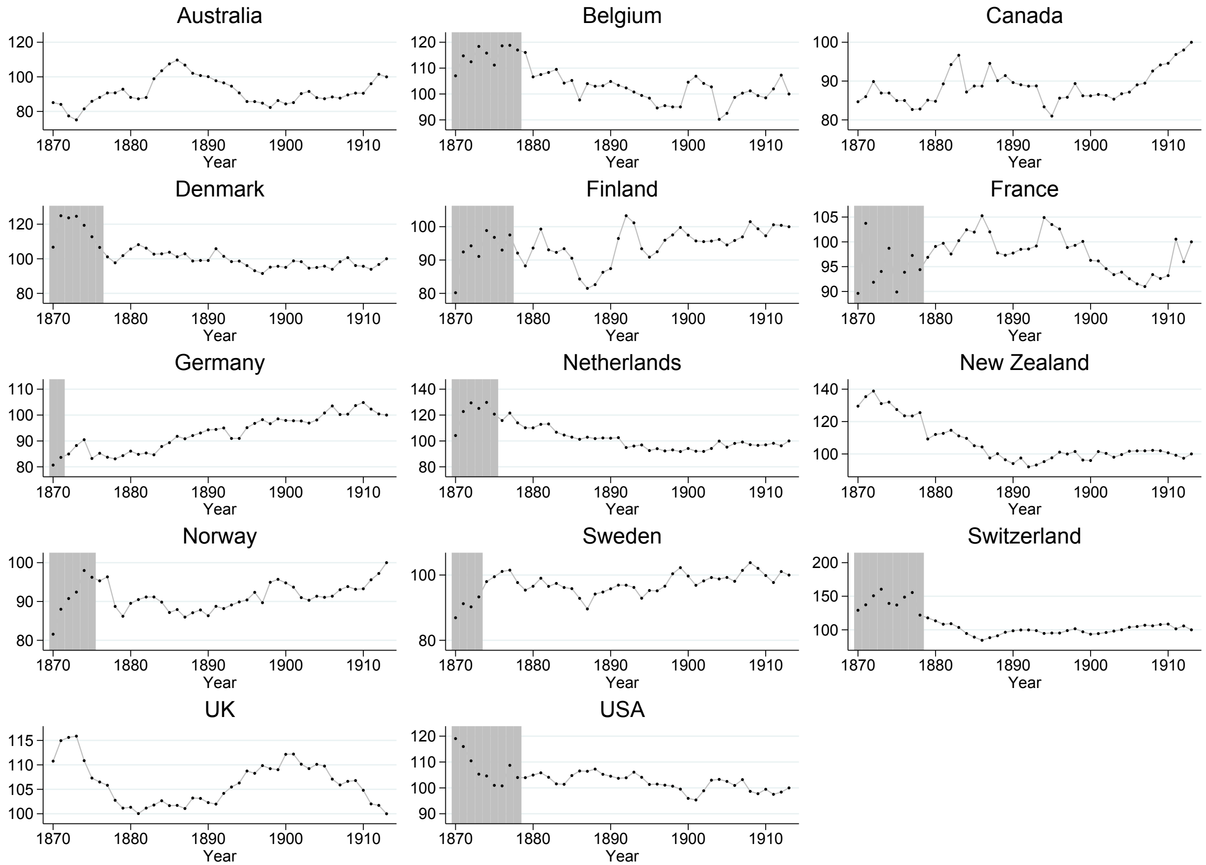
Figure 4.7: *Price level: GDP deflator vs. weighted average of sectoral prices*



Notes: Solid black line – GDP deflator. Dashed gray line – weighted average of sectoral prices (weight = sectoral shares by Buera and Kaboski (2012)).

Real effective exchange rates

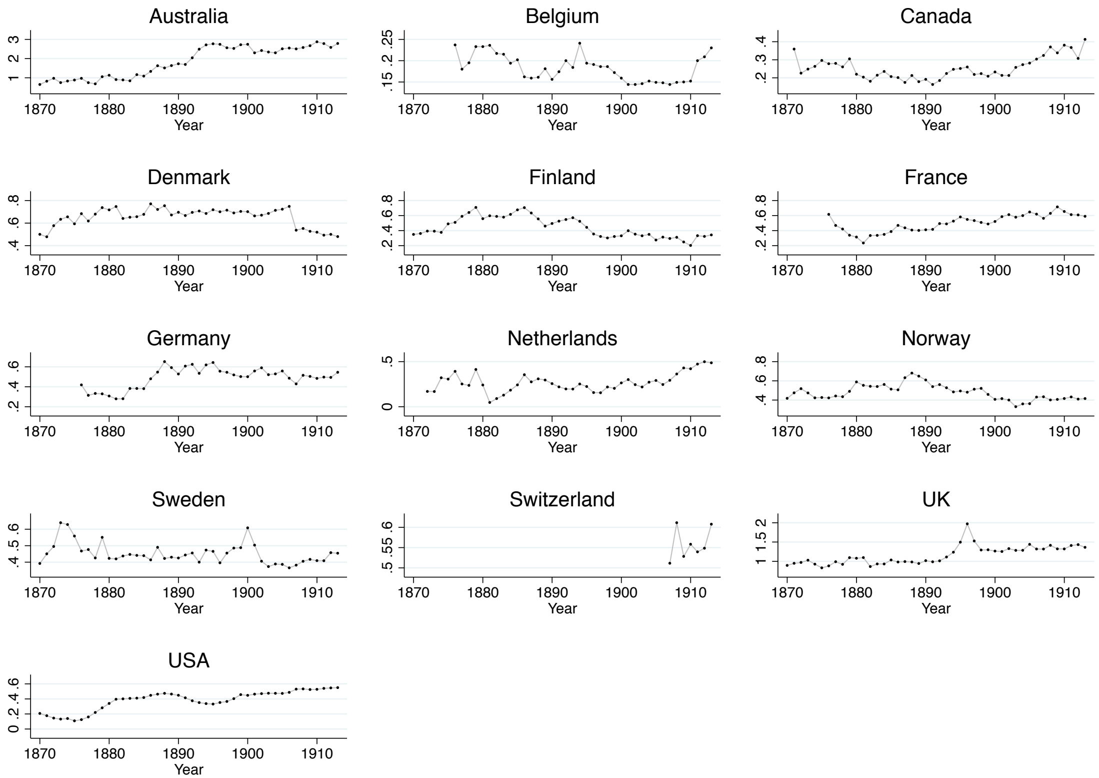
Figure 4.8: *REERs within the Gold Standard*



Notes: Grey – not on Gold Standard.

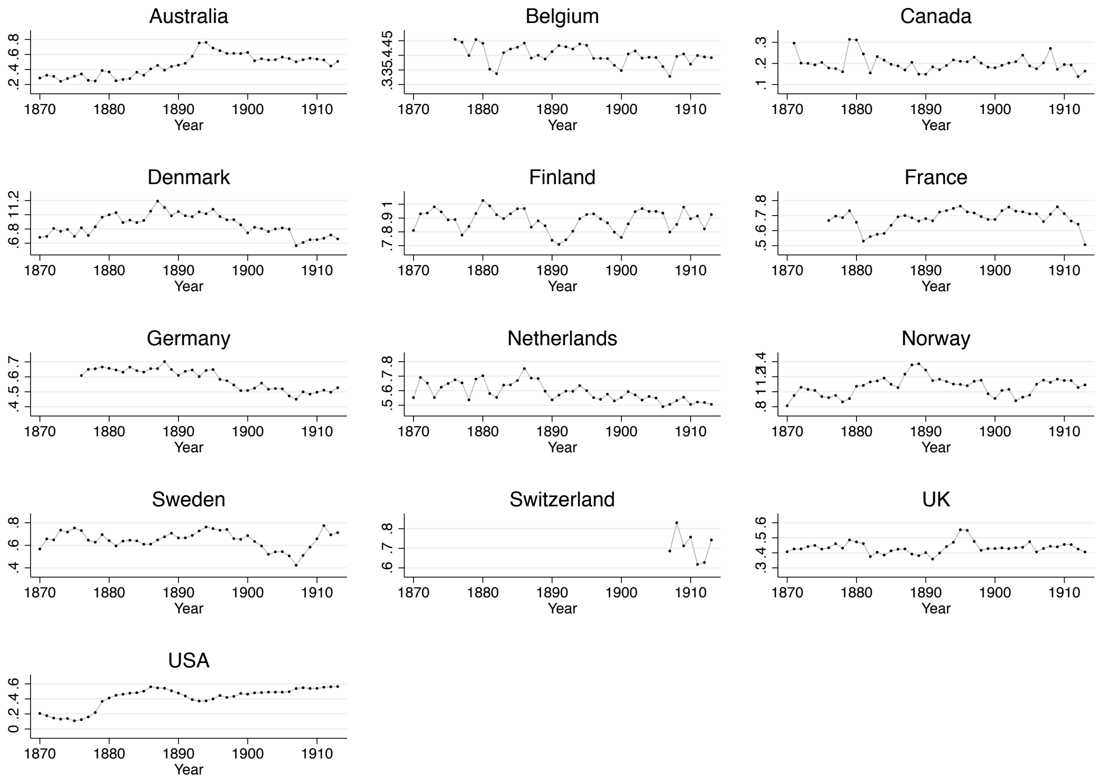
Gold cover ratios

Figure 4.9: *Gold cover ratios, narrow*



Notes: The figure depicts narrowly defined gold cover ratios: Gold cover ratio = Gold divided by central bank notes in circulation. In the absence of a central bank (e.g. Australia, Canada and the U.S.) the gold cover ratio has been calculated as the ratio of gold- and specie reserves in the institution guarateeing gold convertibility (i.e. the Treasury in the U.S. or the private banks in Australia and Canada) relative to bank notes in circulation and demand deposits.

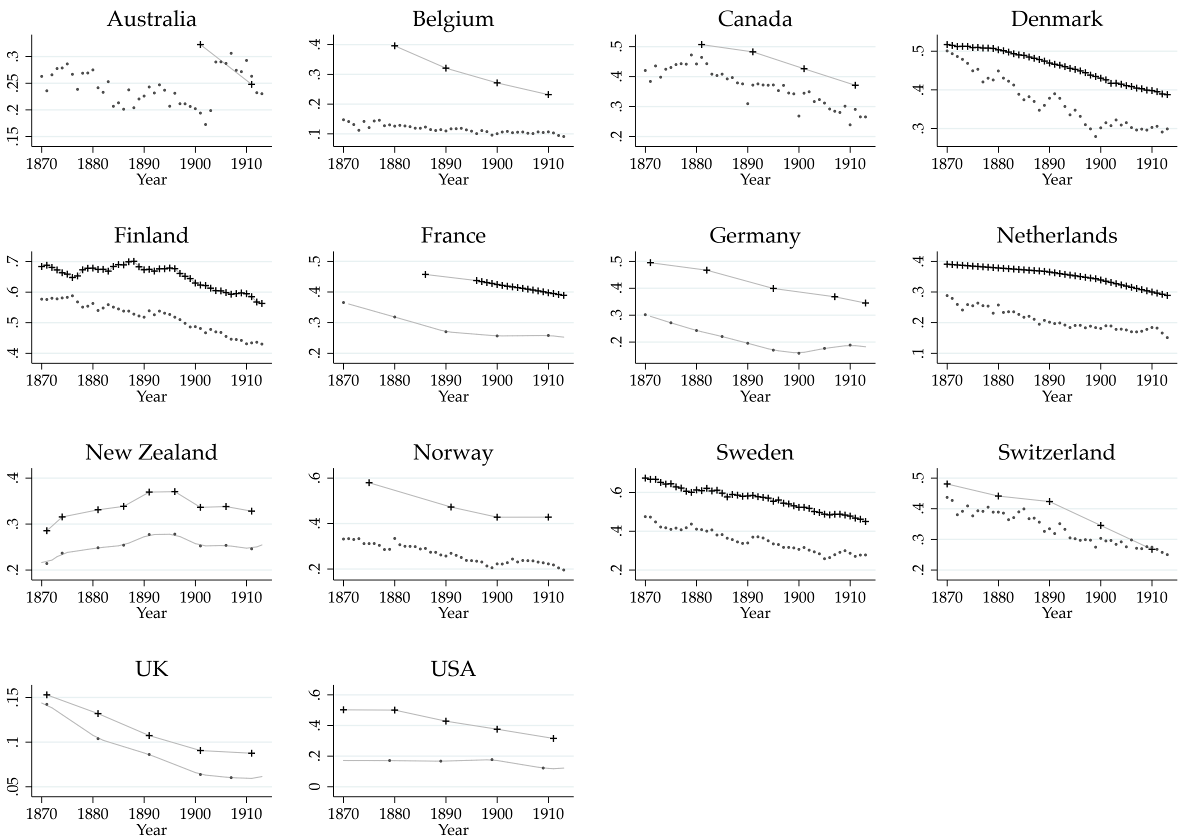
Figure 4.10: *Gold cover ratios, broad*



Notes: The figure depicts broadly defined gold cover ratios: Gold cover ratio = (Metal reserves + foreign exchange reserves)/(central bank notes in circulation + central bank deposits). In the absence of a central bank (e.g. Australia, Canada and the U.S.) the gold cover ratio has been calculated as the ratio of gold-, specie and foreign exchange reserves in the institution guarateeing gold convertibility (i.e. the Treasury in the U.S. or the private banks in Australia and Canada) relative to bank notes in circulation and demand deposits.

Primary sector shares

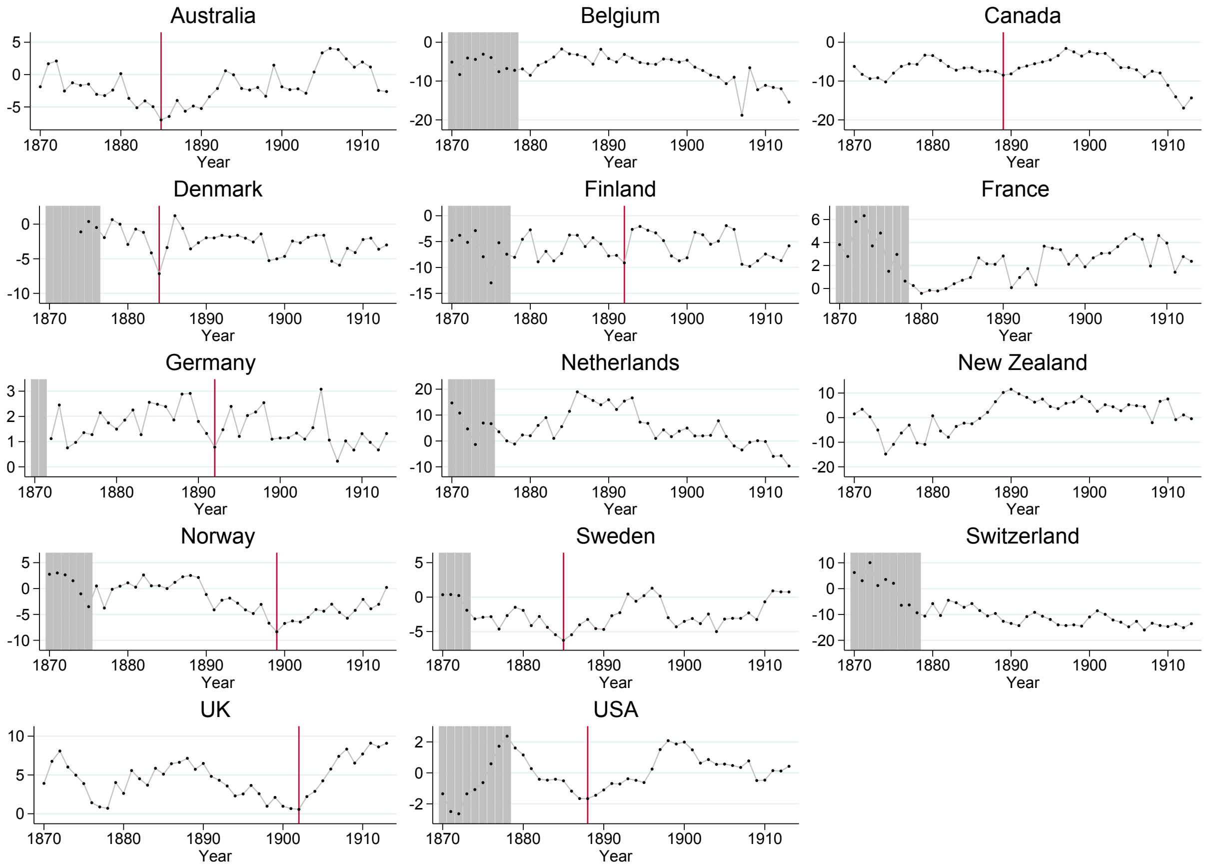
Figure 4.11: *Primary sector shares*



Notes: Plus sign – primary sector employment share (i.e. agriculture and raw materials). Circles – agricultural sector value added share. Plus signs and circles indicate observations. Grey lines are linearly inter- and extrapolated values.

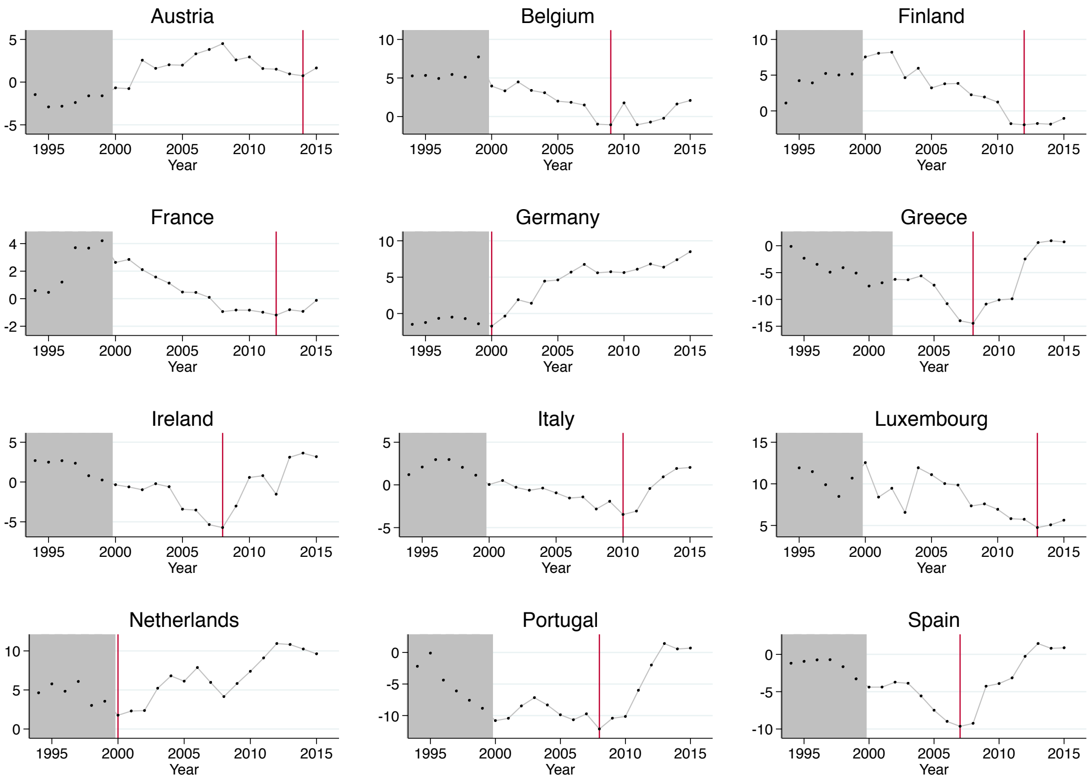
Adjustment periods

Figure 4.12: *CA/GDP within the Gold Standard*



Notes: Grey – not on Gold Standard. Vertical bar – CA/GDP trough. CA/GDP troughs are defined according to a turning-point algorithm à la Bry and Boschan (1971): CA/GDP troughs are defined as the lowest CA/Y-value in a ±10-year window.

Figure 4.13: *CA/GDP within the euro area*



Notes: Grey – not in euro area. Vertical bar – CA/GDP trough. CA/GDP troughs are defined according to a turning-point algorithm à la Bry and Boschan (1971): CA/GDP troughs are defined as the lowest CA/Y-value in a ±8-year window. Border conditions were weakened because of the short sample length.

4.A.4. Additional results

Contemporaneous correlations

Table 4.14: *Prices, migration and monetary policy correlation with the trade balance*

	Δ CA/GDP		
	ρ	p	N
Prices:			
REER	-0.137***	0.00	596
CPI	-0.158***	0.00	596
CPI*	-0.057	0.17	596
Migration:			
Δ Immigration/Pop	-0.293***	0.00	413
Δ Emigration/Pop	0.040	0.35	554
Δ Net Immigration/Pop	-0.311***	0.00	374
Monetary policy:			
Δ Discount rate	-0.147***	0.00	420
Δ Gold cover ratio	0.186***	0.00	497
NEER	0.038	0.35	596

Notes: * 0.10 ** 0.05 *** 0.01. The table shows Pearson correlation coefficients for the CA/GDP ratio (first differences Δ) and prices, migration and monetary policy (first differences Δ or growth rates).

Table 4.15: *Correlation between external adjustment, sectoral prices and sectoral exports*

	Δ CA/GDP		
	ρ	p	N
Disaggregate prices:			
Agricultural	-0.210***	0.00	595
Raw material	-0.062	0.14	572
Industrial	-0.062	0.17	503
Services	-0.170***	0.00	430
Disaggregate exports:			
Agricultural	0.184***	0.00	528
Raw material	0.093**	0.03	518
Industrial	0.120***	0.01	494

Notes: * 0.10 ** 0.05 *** 0.01. The table shows the Pearson correlation coefficients for the CA/GDP ratio (first differences Δ) and the growth rates of sectoral prices and sectoral exports/total exports.

Table 4.16: *Correlation between external adjustment, export prices, import prices and local prices*

	Δ CA/GDP		
	ρ	p	N
Terms of trade	0.059	0.16	561
CPI	-0.158***	0.00	596

	Export prices		
	ρ	p	N
Import prices	0.509***	0.00	522

Notes: * 0.10 ** 0.05 *** 0.01. The table shows the Pearson correlation coefficients for the CA/GDP ratio (first differences Δ) and the growth rates of the terms of trade and the domestic CPI.

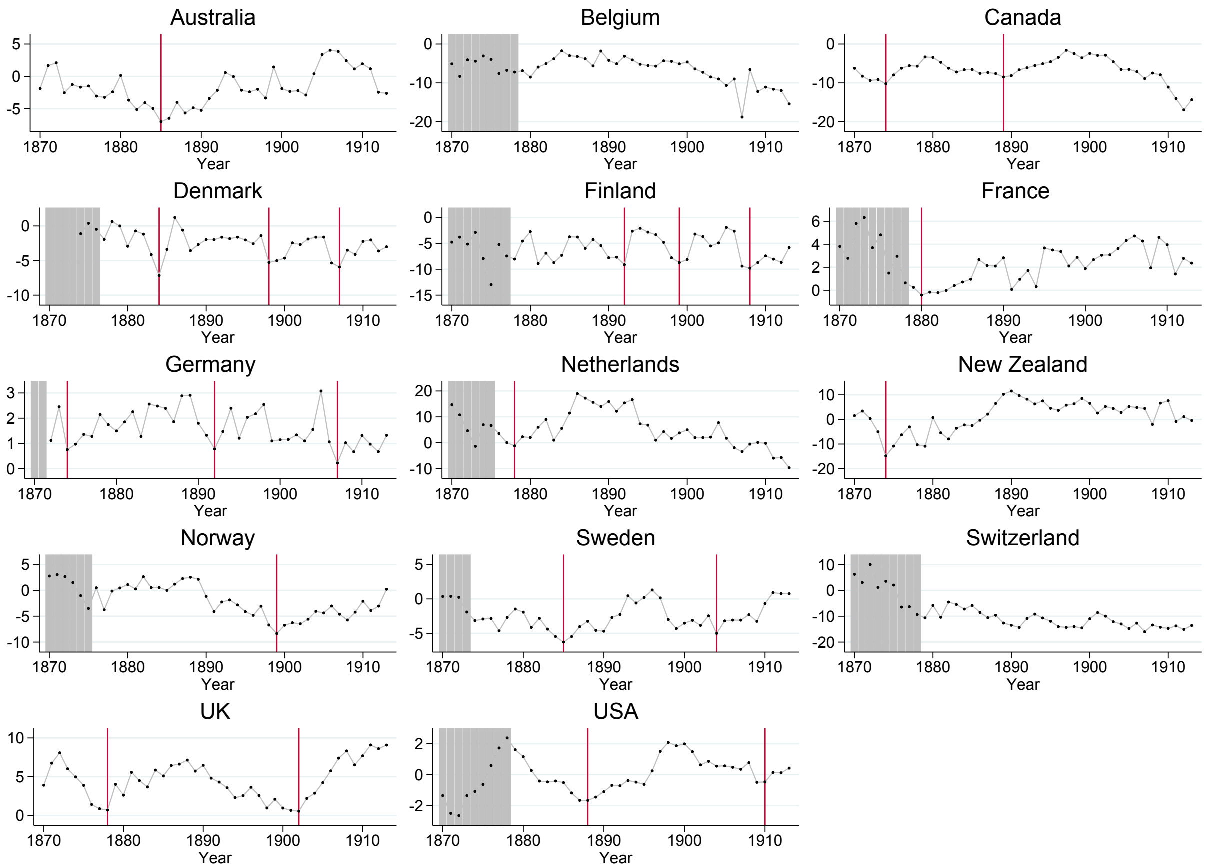
Table 4.17: *Correlation between external adjustment and sectoral adjustment*

	Δ CA/GDP		
	ρ	p	N
Δ Primary sector share	0.107***	0.01	586
Δ Secondary sector share	-0.022	0.61	518
Δ Tertiary sector share	-0.082*	0.06	518

Notes: * 0.10 ** 0.05 *** 0.01. The table shows Pearson correlation coefficients for 2-year changes in the CA/GDP ratio and 2-year changes in the agricultural, industrial and service sector shares.

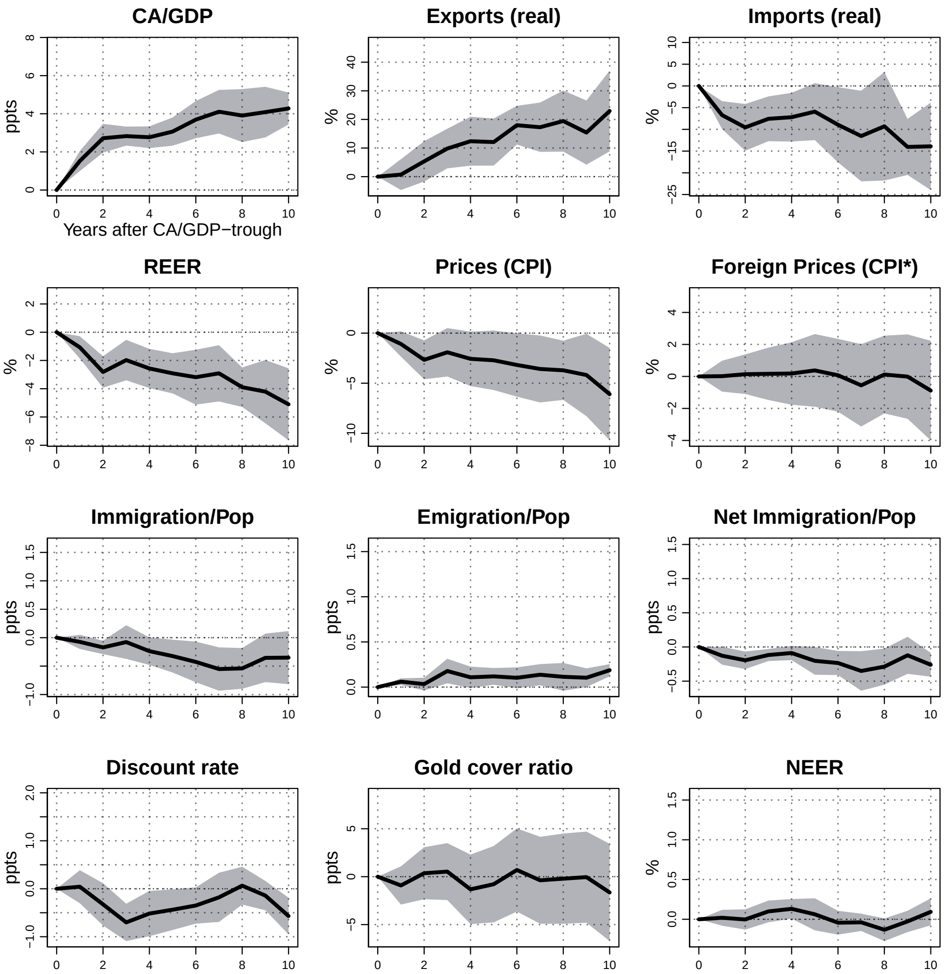
Alternative adjustment periods

Figure 4.14: *CA/GDP within the Gold Standard*



Notes: Grey – not on Gold Standard. Vertical bar – CA/GDP trough. CA/GDP troughs are informally defined as all visually salient CA/GDP troughs.

Figure 4.15: *Alternative adjustment periods: Prices, migration and monetary policy*



Notes: Black solid – Gold Standard. Shaded areas – 90% confidence bands based on robust Driscoll-Kraay standard errors (small sample corrected, autocorrelation lag order = 2 years). CA/GDP troughs are informally defined as all visually salient CA/GDP troughs (see Figure 4.A.3).

Figure 4.16: *Alternative adjustment periods: sectoral prices and sectoral exports*

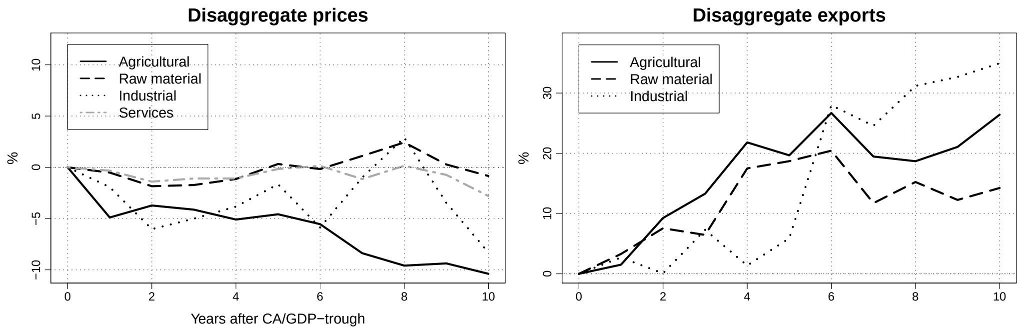


Figure 4.17: *Alternative adjustment periods: terms of trade vs. local prices*

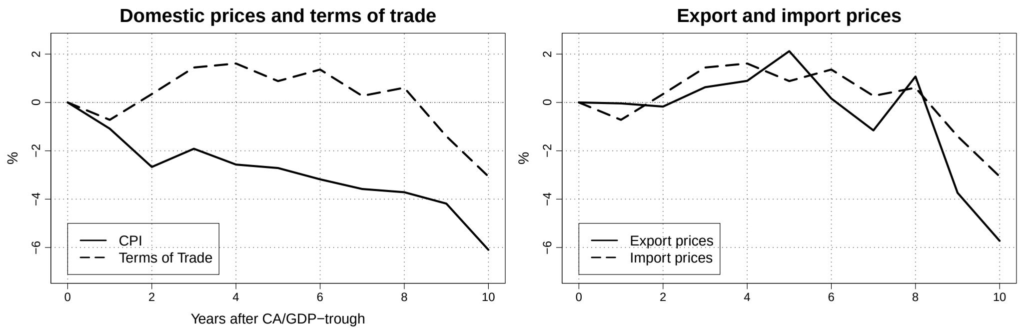
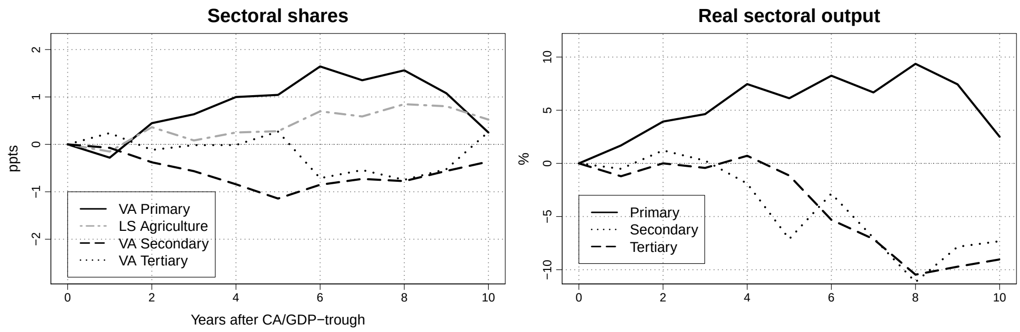


Figure 4.18: *Alternative adjustment periods: sectoral adjustment*

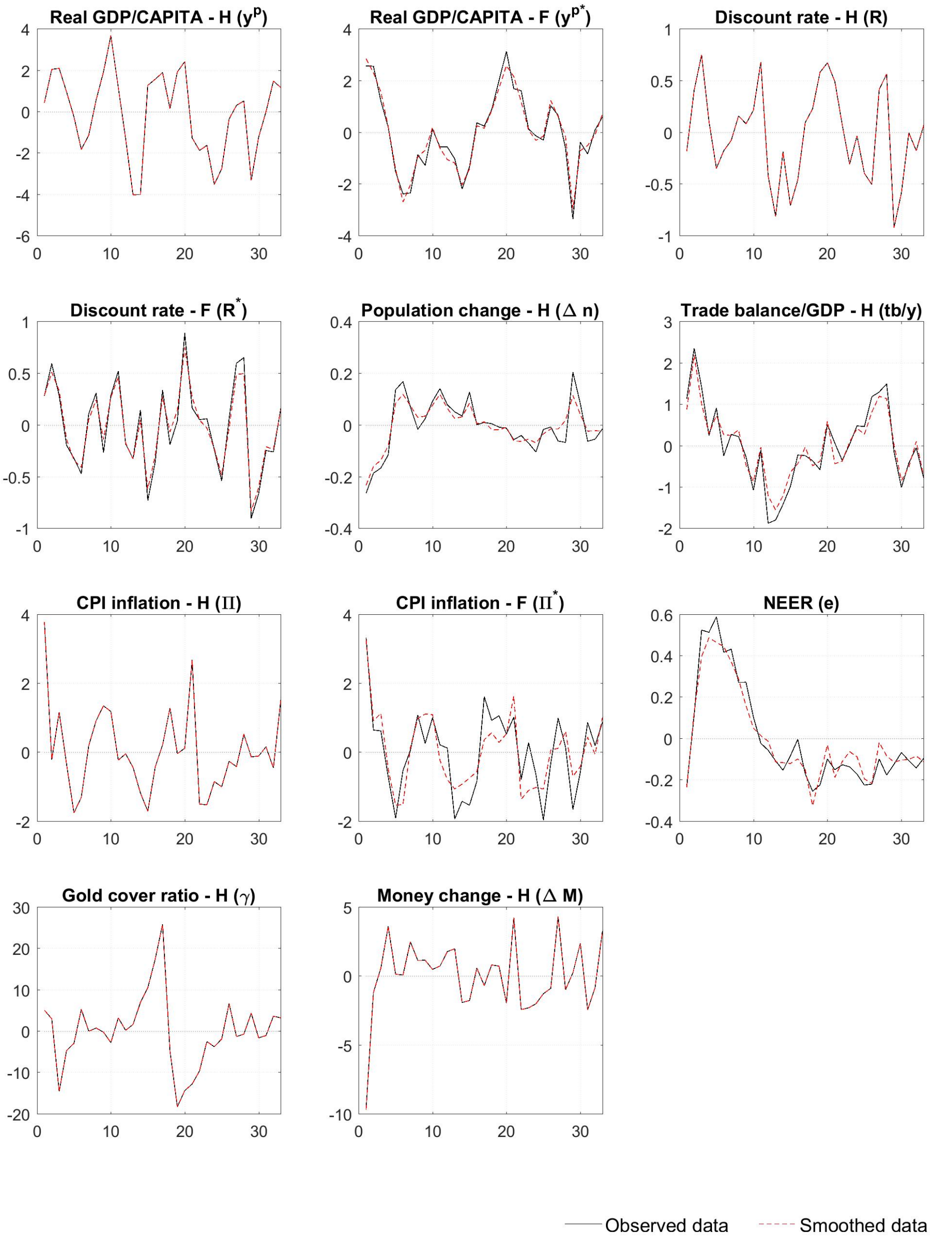


Notes: CA/GDP troughs are informally defined as all visually salient CA/GDP troughs (see Figure 4.A.3).

4.A.5. *Additional model results*

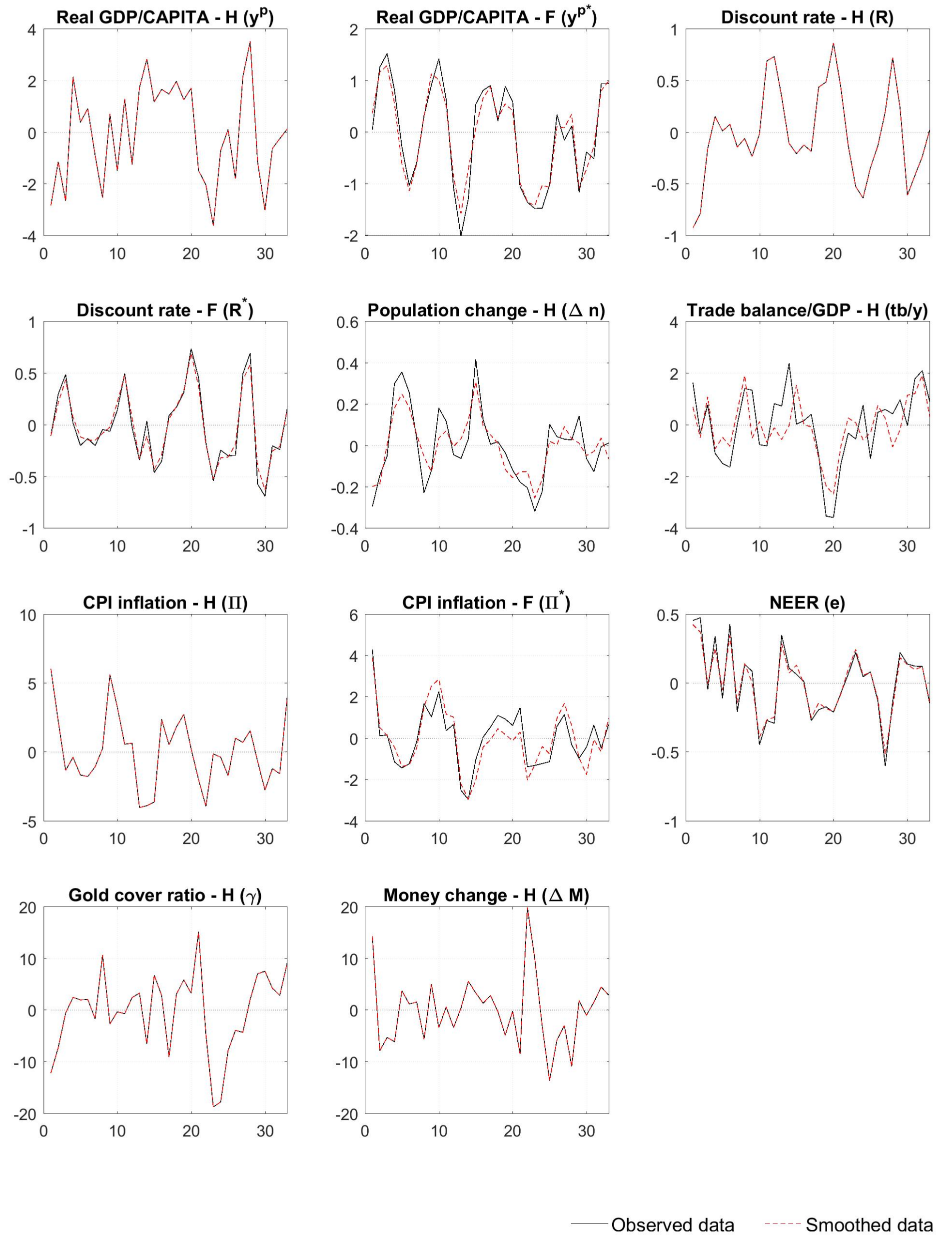
Historical Observations and Smoothed Data

Figure 4.19: *U.K. – Observables and smoothed variables*



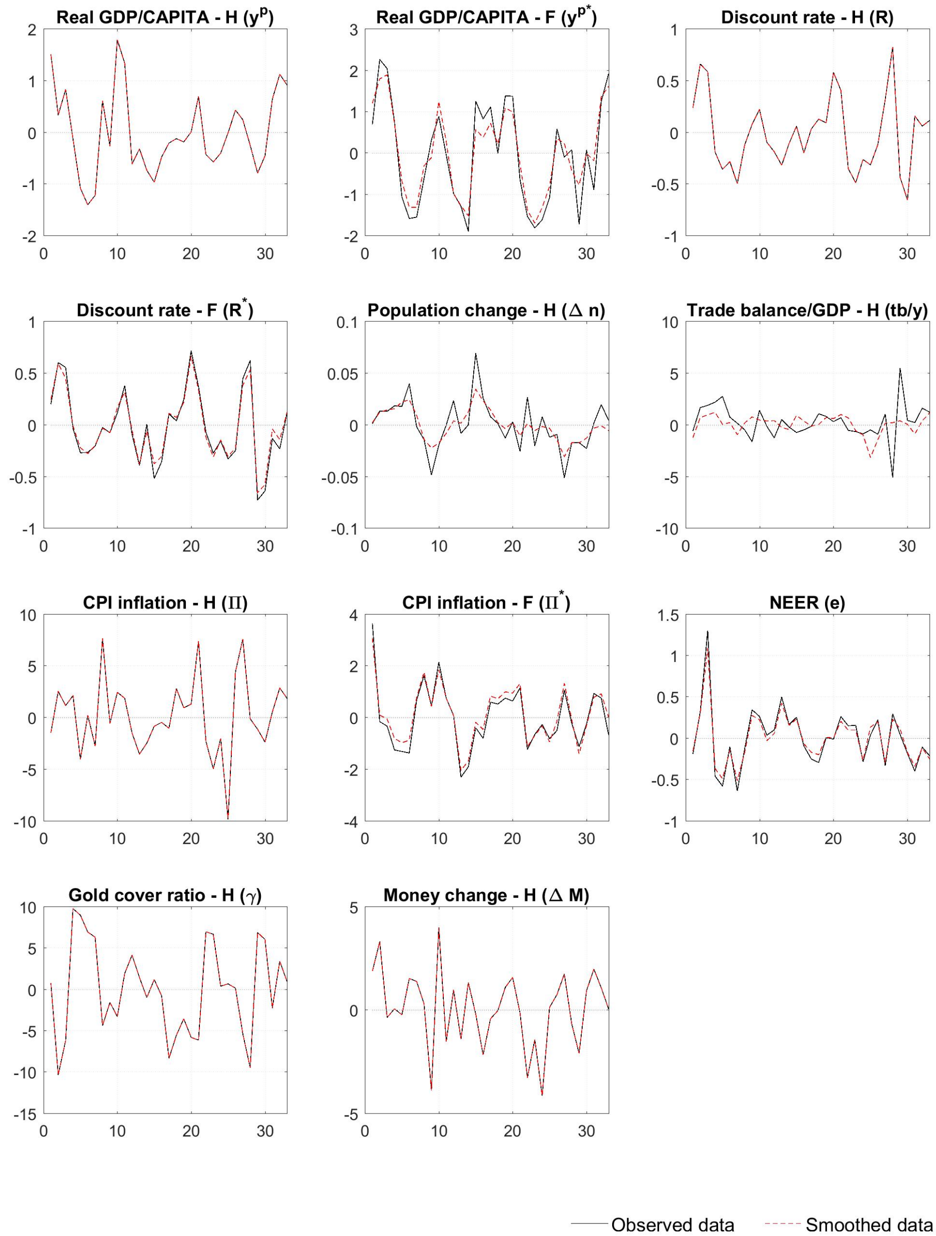
Notes: For variables without measurement error, the smoothed and observed series are identical.

Figure 4.20: *Sweden – Observables and smoothed variables*



Notes: For variables without measurement error, the smoothed and observed series are identical.

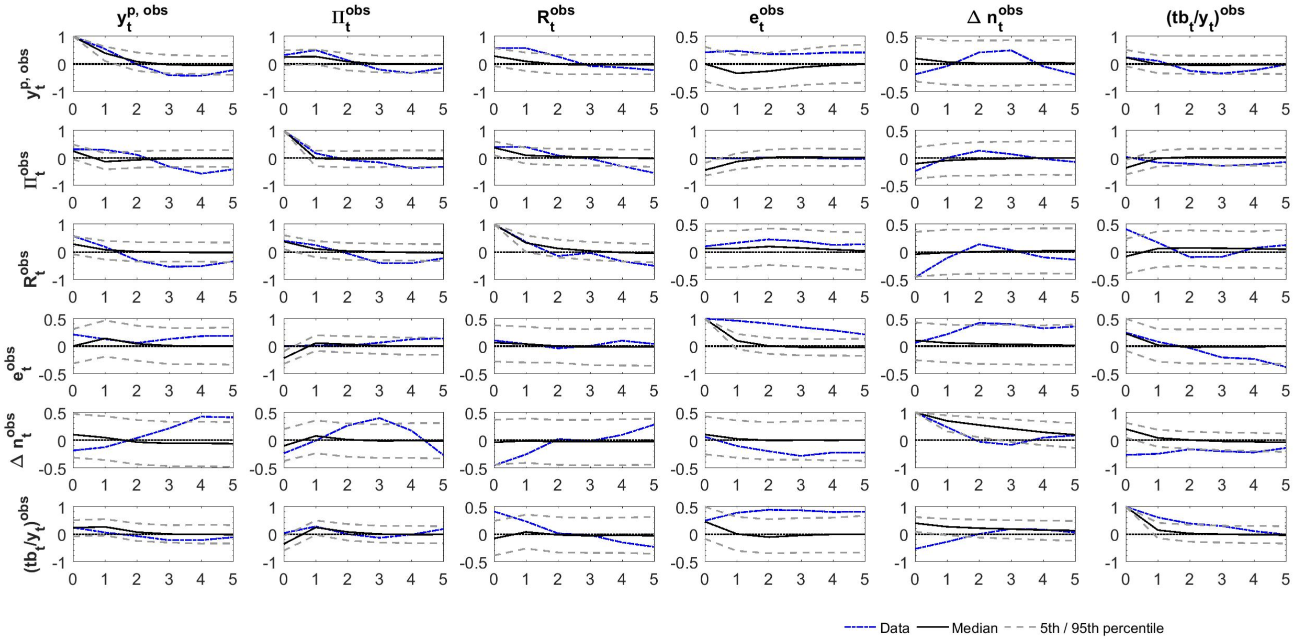
Figure 4.21: *Belgium – Observables and smoothed variables*



Notes: For variables without measurement error, the smoothed and observed series are identical.

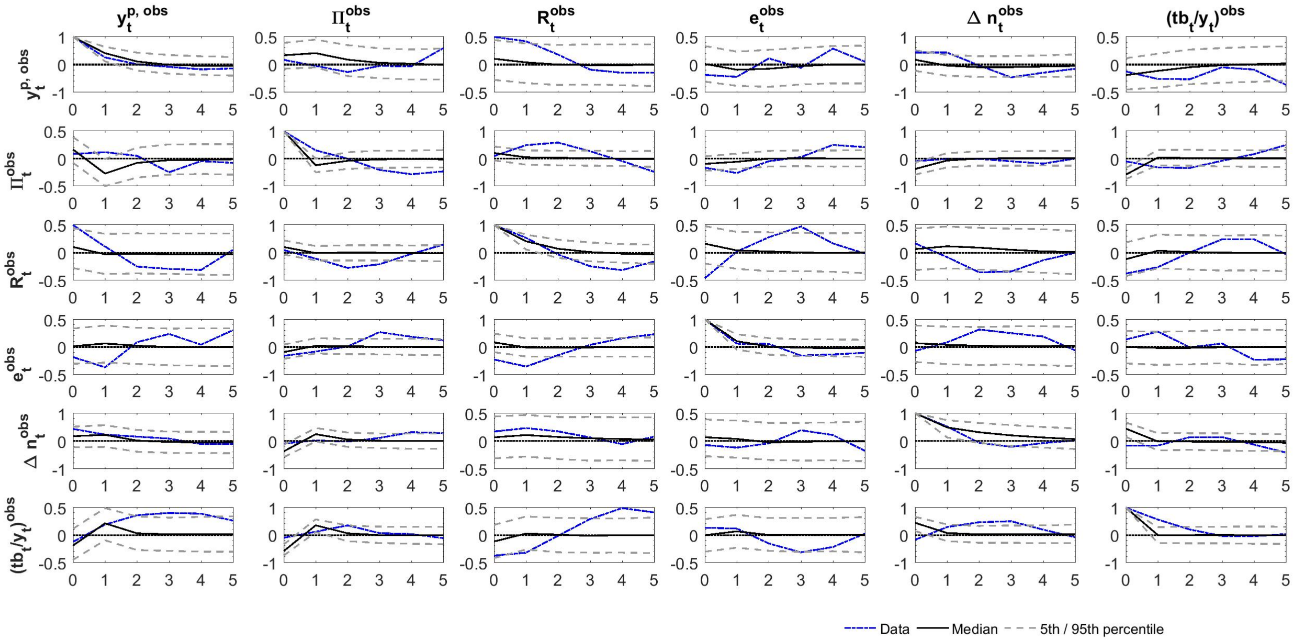
Autocorrelations - Observed vs. Simulated Data

Figure 4.22: *(Auto-)correlations – U.K.*



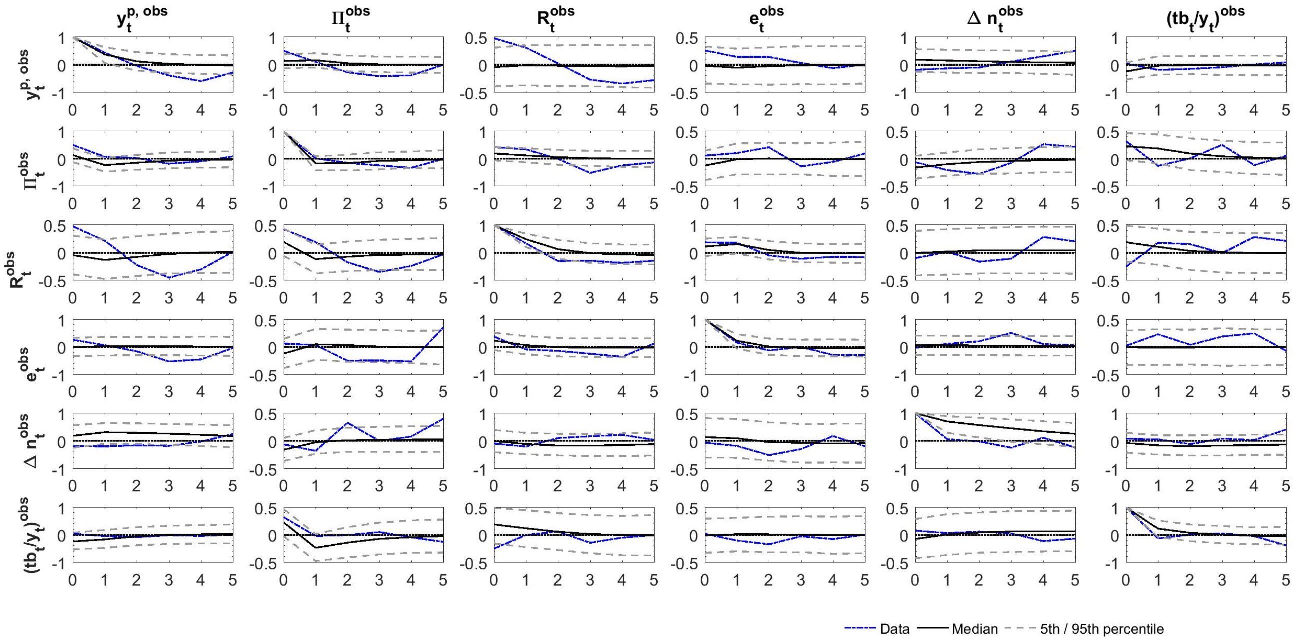
Notes: y-axes indicate correlations. x-axes indicate lags of column variables. Rows show reference variables. Black solid lines – median moment of simulated data. Grey dashed lines – 90 percent coverage percentiles of the simulated data. All simulated moments are based on 2000 simulation runs conditional on the posterior mean. y_t^p – Per capita output, Π_t – CPI inflation, R_t – Discount rate, e_t – Nominal exchange rate, Δn_t – Population change, $tb_t/y_t)$ – Trade balance/output.

Figure 4.23: *(Auto-)correlations – Sweden*



Notes: y-axes indicate correlations. x-axes indicate lags of column variables. Rows show reference variables. Black solid lines – median moment of simulated data. Grey dashed lines – 90 percent coverage percentiles of the simulated data. All simulated moments are based on 2000 simulation runs conditional on the posterior mean. y_t^p – Per capita output, Π_t – CPI inflation, R_t – Discount rate, e_t – Nominal exchange rate, Δn_t – Population change, $tb_t/y_t)$ – Trade balance/output.

Figure 4.24: *(Auto-)correlations – Belgium*



Notes: y-axes indicate correlations. x-axes indicate lags of column variables. Rows show reference variables. Black solid lines – median moment of simulated data. Grey dashed lines – 90 percent coverage percentiles of the simulated data. All simulated moments are based on 2000 simulation runs conditional on the posterior mean. y_t^p – Per capita output, Π_t – CPI inflation, R_t – Discount rate, e_t – Nominal exchange rate, Δn_t – Population change, $tb_t/y_t)$ – Trade balance/output.

Forecast Error Variance Decomposition

Table 4.18: *Forecast error variance deomposition – U.K.*

	η^a	η^{a*}	η^r	η^{r*}	η^g	η^{g*}	η^m	η^{m*}	η^x	η^{x*}	η^b	η^{b*}
At 1 year horizon												
Per capita output - H (y_t^p)	0.15	0.00	0.01	0.01	0.55	0.00	0.09	0.03	0.01	0.13	0.01	0.00
CPI inflation - H (Π_t)	0.32	0.02	0.00	0.01	0.03	0.03	0.15	0.08	0.02	0.33	0.00	0.00
REER ($E_{r,t}$)	0.70	0.03	0.00	0.00	0.17	0.08	0.00	0.00	0.00	0.00	0.00	0.00
Trade balance/output - H (tb_t/y_t)	0.97	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
At 10 years horizon												
Per capita output - H (y_t^p)	0.25	0.03	0.01	0.01	0.49	0.00	0.06	0.02	0.01	0.10	0.01	0.00
CPI inflation - H (Π_t)	0.37	0.02	0.01	0.01	0.04	0.03	0.13	0.07	0.01	0.31	0.01	0.00
REER ($E_{r,t}$)	0.57	0.18	0.00	0.00	0.15	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Trade balance/output - H (tb_t/y_t)	0.93	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Unconditional												
Per capita output - H (y_t^p)	0.23	0.13	0.01	0.01	0.44	0.00	0.05	0.02	0.01	0.09	0.01	0.00
CPI inflation - H (Π_t)	0.37	0.02	0.01	0.01	0.04	0.03	0.13	0.07	0.01	0.31	0.01	0.00
REER ($E_{r,t}$)	0.53	0.25	0.00	0.00	0.13	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Trade balance/output - H (tb_t/y_t)	0.87	0.10	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00

Notes: One-year-, ten-year-, and unconditional FEVDs. η^a – technology shock, η^r – discount rate shock, η^g – markup shock, η^m – gold supply shock, η^x – money demand shock, η^b – risk premium shock.

Table 4.19: *Forecast error variance deomposition – Sweden*

	η^a	η^{a*}	η^r	η^{r*}	η^g	η^{g*}	η^m	η^{m*}	η^x	η^{x*}	η^b	η^{b*}
At 1 year horizon												
Per capita output - H (y_t^p)	0.02	0.00	0.00	0.01	0.87	0.00	0.03	0.02	0.01	0.04	0.00	0.00
CPI inflation - H (Π_t)	0.50	0.01	0.05	0.05	0.06	0.01	0.04	0.04	0.02	0.13	0.07	0.02
REER ($E_{r,t}$)	0.64	0.03	0.00	0.02	0.10	0.14	0.02	0.03	0.01	0.01	0.00	0.01
Trade balance/output - H (tb_t/y_t)	0.72	0.02	0.01	0.11	0.04	0.02	0.03	0.02	0.01	0.01	0.00	0.02
At 10 years horizon												
Per capita output - H (y_t^p)	0.16	0.04	0.00	0.01	0.73	0.00	0.02	0.01	0.01	0.03	0.00	0.00
CPI inflation - H (Π_t)	0.55	0.02	0.04	0.04	0.06	0.01	0.03	0.04	0.01	0.10	0.08	0.02
REER ($E_{r,t}$)	0.58	0.15	0.00	0.01	0.11	0.10	0.01	0.02	0.00	0.00	0.00	0.00
Trade balance/output - H (tb_t/y_t)	0.70	0.04	0.01	0.08	0.06	0.02	0.03	0.02	0.01	0.01	0.00	0.02
Unconditional												
Per capita output - H (y_t^p)	0.16	0.08	0.00	0.01	0.69	0.00	0.02	0.01	0.01	0.03	0.00	0.00
CPI inflation - H (Π_t)	0.54	0.03	0.04	0.05	0.06	0.01	0.03	0.04	0.01	0.10	0.08	0.02
REER ($E_{r,t}$)	0.57	0.17	0.00	0.01	0.11	0.10	0.02	0.02	0.00	0.01	0.00	0.00
Trade balance/output - H (tb_t/y_t)	0.59	0.11	0.01	0.09	0.07	0.02	0.03	0.03	0.01	0.02	0.00	0.02

Notes: One-year-, ten-year-, and unconditional FEVDs. η^a – technology shock, η^r – discount rate shock, η^g – markup shock, η^m – gold supply shock, η^x – money demand shock, η^b – risk premium shock.

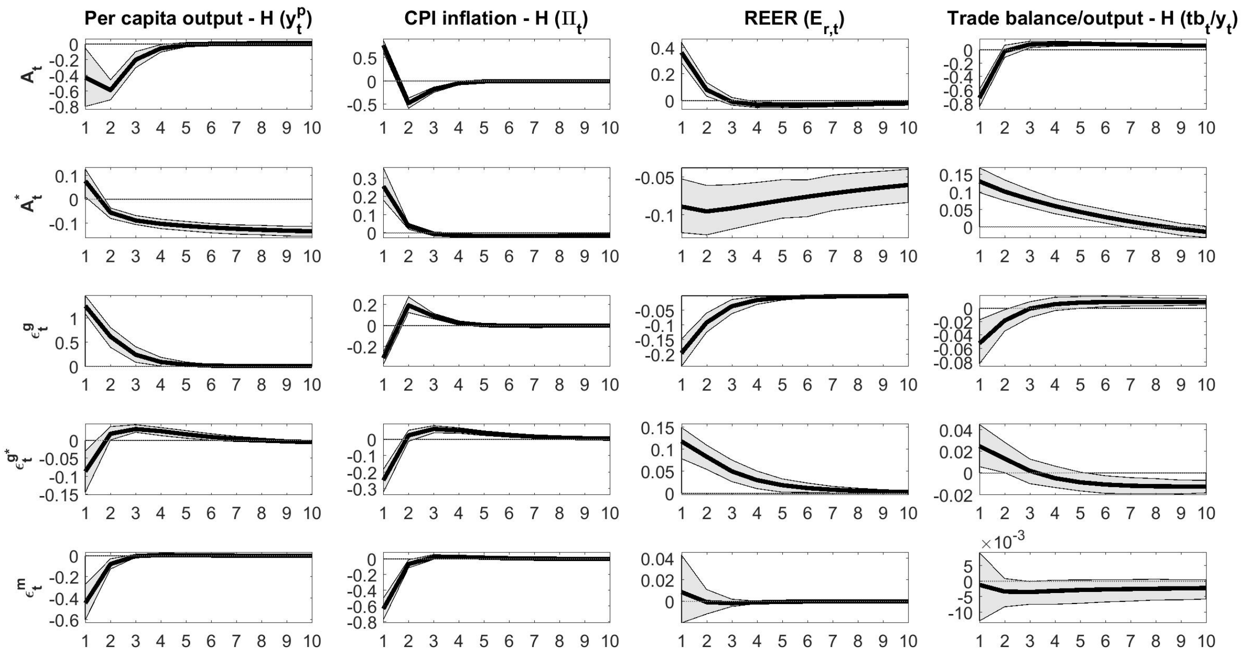
Table 4.20: *Forecast error variance deomposition – Belgium*

	η^a	η^{a*}	η^r	η^{r*}	η^g	η^{g*}	η^m	η^{m*}	η^x	η^{x*}	η^b	η^{b*}
At 1 year horizon												
Per capita output - H (y_t^p)	0.10	0.04	0.00	0.02	0.58	0.22	0.01	0.00	0.00	0.02	0.00	0.01
CPI inflation - H (Π_t)	0.50	0.13	0.10	0.02	0.08	0.00	0.04	0.01	0.00	0.07	0.03	0.01
REER ($E_{r,t}$)	0.60	0.04	0.00	0.02	0.11	0.13	0.01	0.01	0.00	0.04	0.00	0.02
Trade balance/output - H (tb_t/y_t)	0.11	0.12	0.01	0.09	0.47	0.10	0.00	0.01	0.00	0.06	0.00	0.03
At 10 years horizon												
Per capita output - H (y_t^p)	0.09	0.14	0.00	0.03	0.39	0.23	0.01	0.01	0.00	0.07	0.00	0.02
CPI inflation - H (Π_t)	0.50	0.15	0.06	0.02	0.09	0.01	0.04	0.01	0.00	0.07	0.04	0.01
REER ($E_{r,t}$)	0.59	0.08	0.00	0.02	0.09	0.15	0.01	0.01	0.00	0.04	0.00	0.01
Trade balance/output - H (tb_t/y_t)	0.21	0.16	0.01	0.07	0.33	0.10	0.01	0.01	0.00	0.09	0.00	0.03
Unconditional												
Per capita output - H (y_t^p)	0.09	0.13	0.00	0.04	0.32	0.21	0.02	0.02	0.00	0.14	0.00	0.02
CPI inflation - H (Π_t)	0.49	0.16	0.06	0.02	0.09	0.01	0.04	0.01	0.00	0.08	0.04	0.02
REER ($E_{r,t}$)	0.55	0.08	0.00	0.02	0.08	0.17	0.01	0.01	0.00	0.06	0.00	0.02
Trade balance/output - H (tb_t/y_t)	0.16	0.16	0.01	0.09	0.24	0.10	0.01	0.02	0.00	0.18	0.00	0.04

Notes: One-year-, ten-year-, and unconditional FEVDs. η^a – technology shock, η^r – discount rate shock, η^g – markup shock, η^m – gold supply shock, η^x – money demand shock, η^b – risk premium shock.

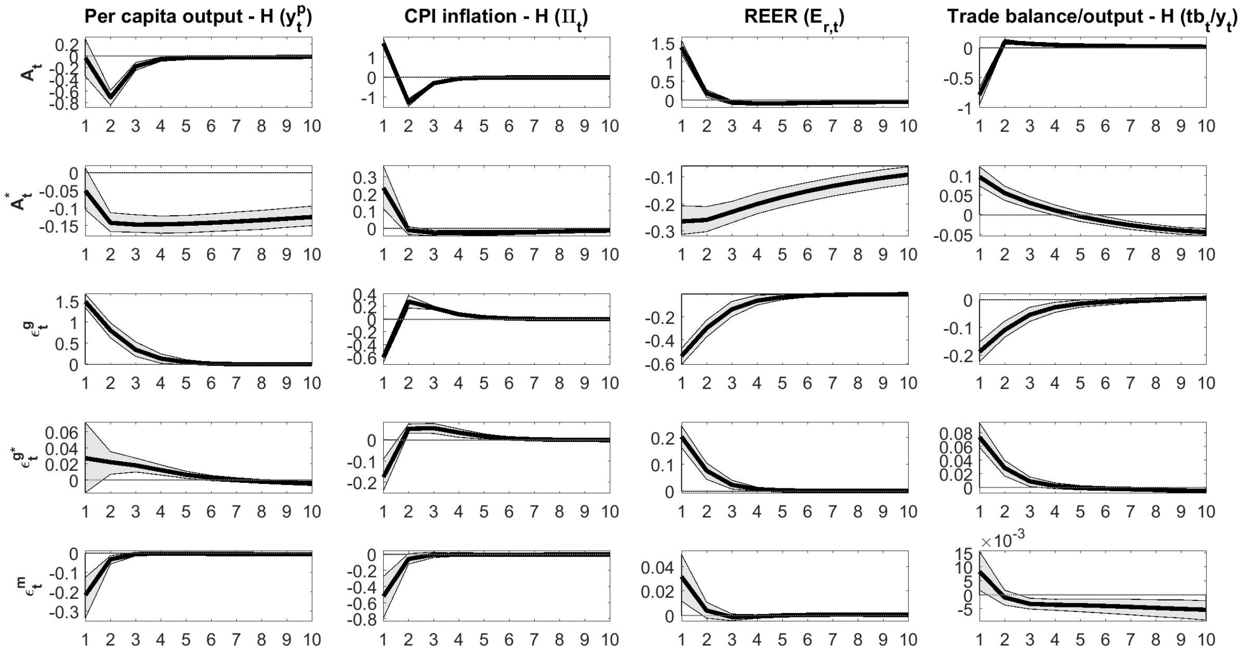
Bayesian Impulse Responses

Figure 4.25: *Bayesian IRF - U.K.*



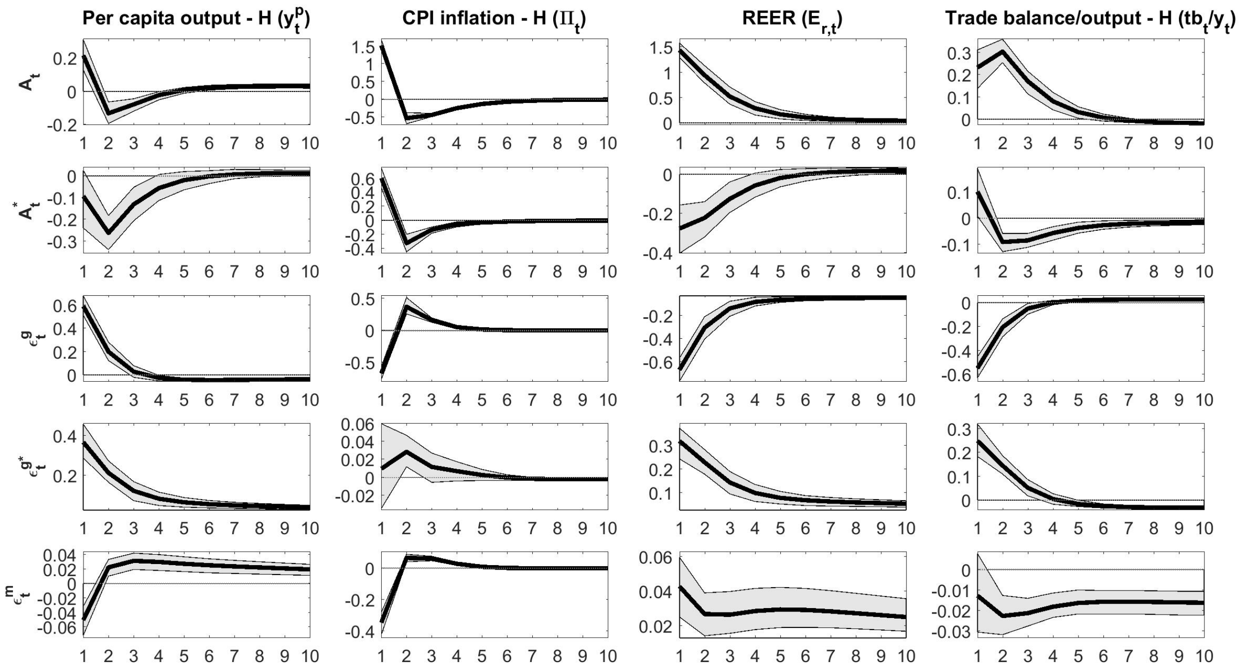
Notes: The graphic depicts Bayesian impulse responses to *negative* shocks. y_t^p, Π_t and $E_{r,t}$ are displayed as percentage deviations from steady state. tb_t/y_t is displayed in percentage point deviations from steady state. A_t – technology shock H, A_t^* – technology shock F, ϵ_t^g – markup shock H, $\epsilon_t^{g^*}$ – markup shock F, ϵ_t^m – gold shock.

Figure 4.26: *Bayesian IRF -Sweden*



Notes: The graphic depicts Bayesian impulse responses to *negative* shocks. y_t^p, Π_t and $E_{r,t}$ are displayed as percentage deviations from steady state. tb_t/y_t is displayed in percentage point deviations from steady state. A_t – technology shock H, A_t^* – technology shock F, ϵ_t^g – markup shock H, $\epsilon_t^{g^*}$ – markup shock F, ϵ_t^m – gold shock.

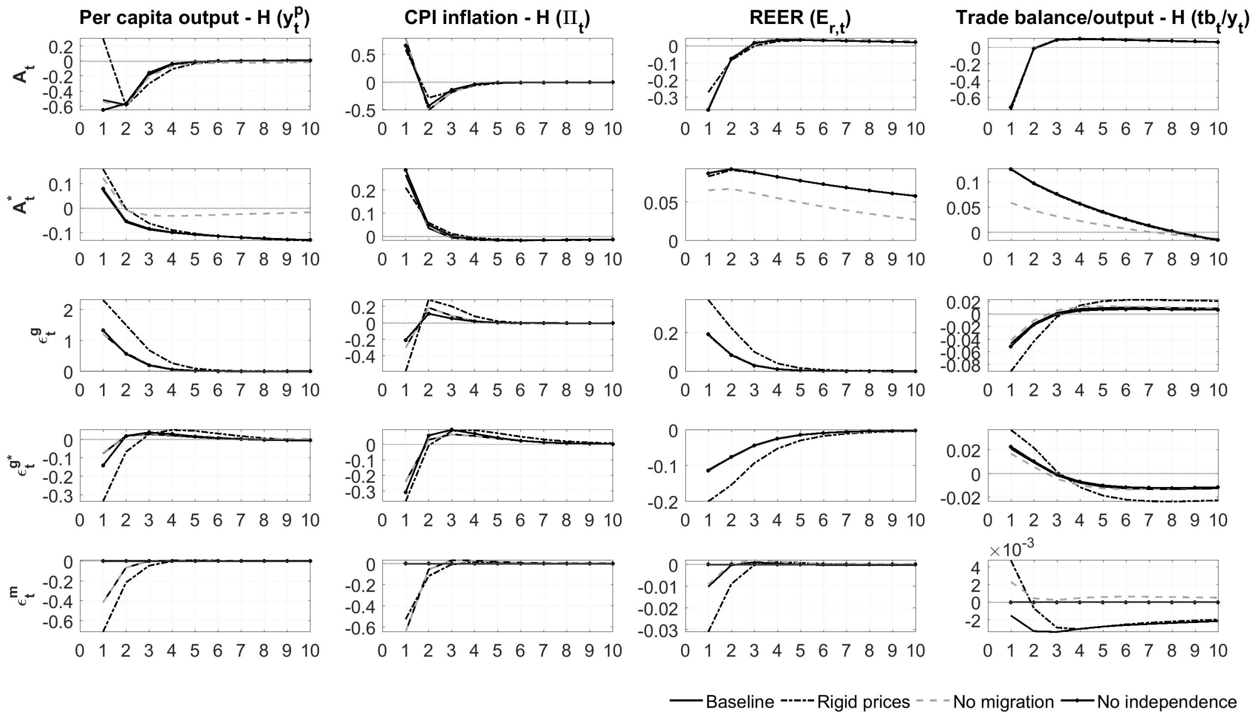
Figure 4.27: *Bayesian IRF -Belgium*



Notes: The graphic depicts Bayesian impulse responses to *negative* shocks. y_t^p, Π_t and $E_{r,t}$ are displayed as percentage deviations from steady state. tb_t/y_t is displayed in percentage point deviations from steady state. A_t – technology shock H, A_t^* – technology shock F, ϵ_t^g – markup shock H, $\epsilon_t^{g^*}$ – markup shock F, ϵ_t^m – gold shock.

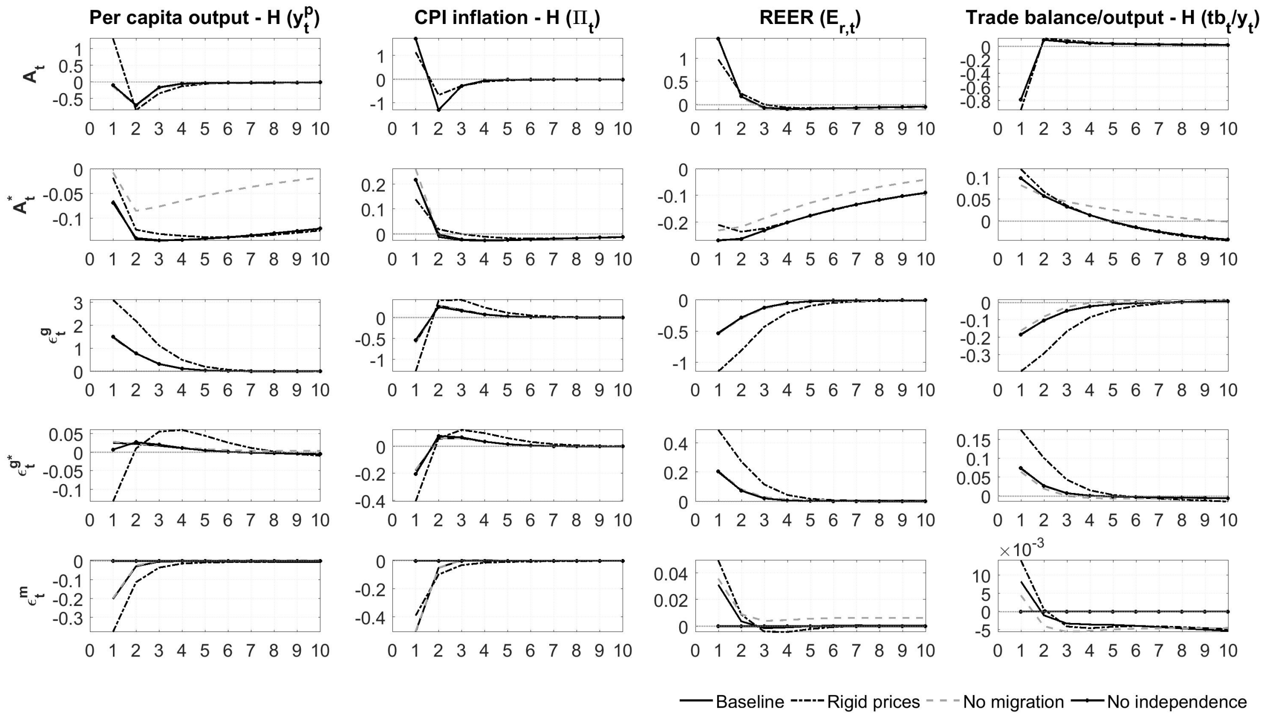
Baseline and Counterfactual Impulse Responses

Figure 4.28: *IRF baseline and counterfactual - U.K.*



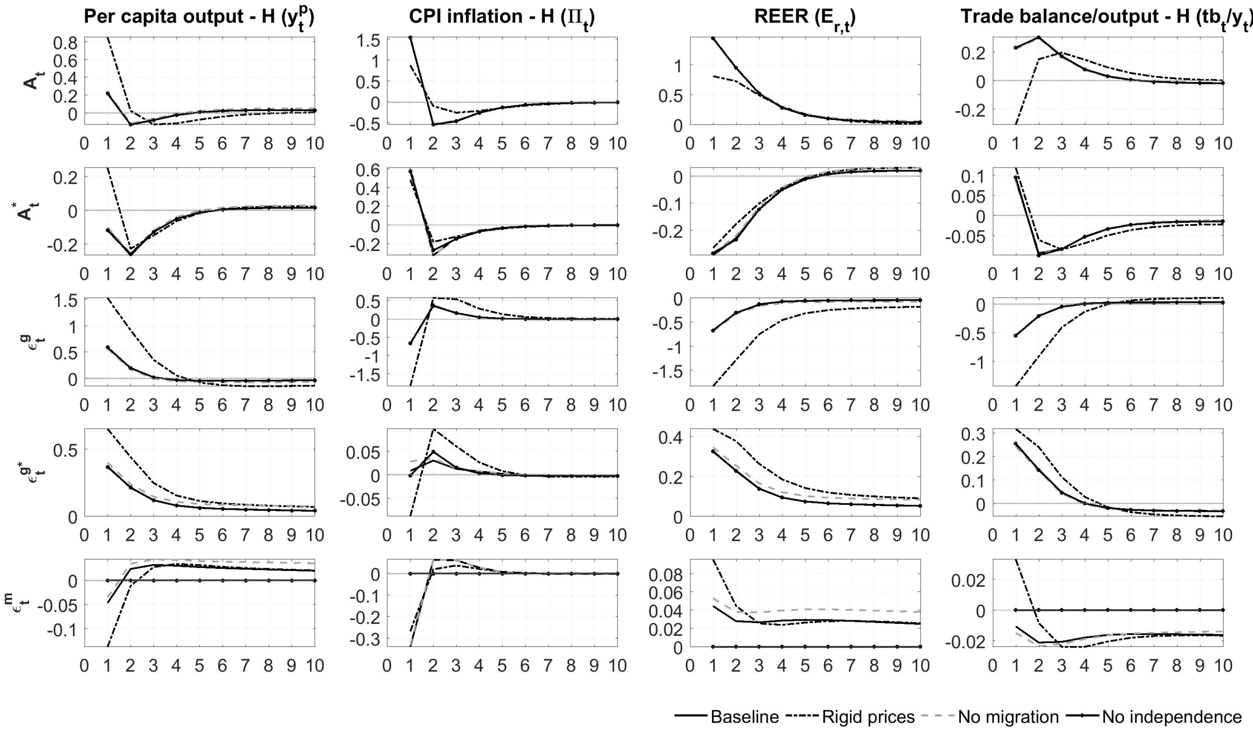
Notes: The graphic depicts the impulse responses to *negative* one standard deviation shocks. y_t^p, Π_t and $E_{r,t}$ are displayed as percentage deviations from steady state. tb_t/y_t is displayed in percentage point deviations from steady state. A_t – technology shock H, A_t^* – technology shock F, ϵ_t^g – markup shock H, $\epsilon_t^{g^*}$ – markup shock F, ϵ_t^m – gold shock.

Figure 4.29: *IRF baseline and counterfactual - Sweden*



Notes: The graphic depicts the impulse responses to *negative* one standard deviation shocks. y_t^p, Π_t and $E_{r,t}$ are displayed as percentage deviations from steady state. tb_t/y_t is displayed in percentage point deviations from steady state. A_t – technology shock H, A_t^* – technology shock F, ϵ_t^g – markup shock H, $\epsilon_t^{g^*}$ – markup shock F, ϵ_t^m – gold shock.

Figure 4.30: *IRF baseline and counterfactual - Beglium*



Notes: The graphic depicts the impulse responses to *negative* one standard deviation shocks. y_t^p, Π_t and $E_{r,t}$ are displayed as percentage deviations from steady state. tb_t/y_t is displayed in percentage point deviations from steady state. A_t – technology shock H, A_t^* – technology shock F, ϵ_t^g – markup shock H, $\epsilon_t^{g^*}$ – markup shock F, ϵ_t^m – gold shock.

Additional counterfactual volatilities (baseline model)

Table 4.21: *Counterfactual volatility*

		Baseline model (1)	Rigid prices (2)	No migration (3)	No independence (4)	No migration, given rigid prices (3∣2)	No independence, given rigid prices (4∣2)
United Kingdom							
y_t^p	Per capita output	1.76	3.20	1.75	1.82	3.19	3.42
			(81.50%)	(-0.89%)	(3.19%)	(-0.16%)	(7.03%)
Π_t	Inflation	1.73	1.56	1.73	1.51	1.56	1.39
			(-9.61%)	(-0.06%)	(-12.47%)	(-0.01%)	(-10.93%)
$E_{r,t}$	REER	0.49	0.61	0.48	0.50	0.60	0.63
			(23.93%)	(-3.74%)	(1.20%)	(-2.01%)	(3.14%)
tb_t/y_t	Trade balance/output	0.81	0.84	0.77	0.80	0.80	0.84
			(4.32%)	(-4.91%)	(-0.22%)	(-4.94%)	(-0.18%)
Sweden							
y_t^p	Per capita output	1.88	4.26	1.87	1.90	4.28	4.38
			(126.77%)	(-0.20%)	(0.91%)	(0.46%)	(2.82%)
Π_t	Inflation	2.64	2.28	2.62	2.57	2.28	2.19
			(-13.69%)	(-0.58%)	(-2.81%)	(-0.13%)	(-3.74%)
$E_{r,t}$	REER	1.65	1.88	1.64	1.66	1.89	1.89
			(13.79%)	(-1.13%)	(0.15%)	(0.19%)	(0.67%)
tb_t/y_t	Trade balance/output	0.87	1.16	0.84	0.87	1.08	1.17
			(33.94%)	(-2.91%)	(0.03%)	(-6.93%)	(0.64%)
Belgium							
y_t^p	Per capita output	0.94	2.29	0.97	0.93	2.29	2.29
			(145.15%)	(3.77%)	(-0.19%)	(-0.01%)	(-0.16%)
Π_t	Inflation	2.13	2.39	2.13	2.10	2.42	2.37
			(12.32%)	(0.38%)	(-1.22%)	(1.17%)	(-0.83%)
$E_{r,t}$	REER	1.96	2.61	2.00	1.96	2.69	2.60
			(32.96%)	(1.87%)	(-0.24%)	(2.88%)	(-0.20%)
tb_t/y_t	Trade balance/output	0.84	1.90	0.81	0.84	1.80	1.90
			(127.05%)	(-3.22%)	(0.08%)	(-5.18%)	(0.23%)

Notes: Percentage change in counterfactual S.D. relative to baseline S.D. in parenthesis. Rigid prices – model with rigid prices. No migration – model without migration. No independence – model without policy independence for central bank.

Various robustness checks on model estimation and simulation

Bayesian estimation of a hybrid model

The two-region baseline model in the main text abstracts from those countries that were not part of the Gold Standard (GS). Catão and Solomou (2005) point out that external adjustment of GS countries was facilitated by their trade with non-GS countries. As a robustness check we therefore also estimated a version of the model in which we treat the *F*-region as a hybrid region that includes gold, as well as non-gold countries. We treat the U.K. as the *H*-region.

The distinguishing feature of the hybrid region is that its nominal exchange rate with respect to the home region (the GS country) is more flexible than if the foreign region was a strict adherent to the GS. This allows us to analyze whether our baseline results are robust to larger fluctuations in the nominal effective exchange rate (NEER).

We collected new price level series, exchange rates, short-term rates and real per capita GDP indices for 12 non-gold block countries (Argentina, Brazil, Chile, China, Greece, India, Italy, Japan, Mexico, Portugal, Spain, Russia). On the basis of this data we then calculated global trade-weighted averages which we treat as the *F*-region observables for the hybrid model estimation: trade-weighted short-term rates and per capita GDP series, as well as REER and NEER series that encompass the non-gold block. All other observables remain the same as in the baseline U.K. model estimation.

Most of the estimated parameters are similar to those of the baseline model. Reassuringly, the estimated monetary policy parameters reflect the hybrid setup. In particular, compared to our baseline model, the *H*-region's monetary policy now reacts less to the NEER (0.14 in the hybrid setup, 0.72 in the baseline model). *F*-region's monetary policy also reacts less to both its NEER (0.16 in hybrid setup, 1.62 in baseline model).

Table 4.22, panel A presents the counterfactual model simulations for the estimated hybrid model. We find that, even when the higher degree of NEER flexibility is taken into account, it is still price flexibility that explains most of the benign adjustment experience under the GS.

Extended two-sector model

Appendix 4.A.2 presents a two-sector version of the GS model. Here we report the counterfactual simulation volatilities it gives rise to.[79]

Based on the extended model, we can mimic the 20th century shift away from primary goods production in order to take a look at the counterfactual volatilities this implies. Through the lens of the extended model the 20th century sectoral shift is represented by the following parameter changes. First, non-tradable goods and services, have become more important over time as inputs to wholesale tradable goods (e.g. R&D). This is reflected by a lower value for $\tilde{\phi}$. We set $\tilde{\phi} = 0.8$ (as opposed to 0.9 during the early 20th century), which is consistent with recent input-output tables.

Second, the composition of households' consumption has shifted towards non-tradable services, which can be captured as a decrease in the weight of wholesale tradable goods in the final consumption bundle, i.e. a lower $\tilde{\gamma}$ and $\tilde{\gamma}^{\star}$. Another reason for why $\tilde{\gamma}$ and $\tilde{\gamma}^{\star}$ have become smaller is that retail tradable goods require a larger amount of local distribution services today than 100 years ago (e.g. marketing and retail sales).[80] We calibrate these two

[79]The model calibration is described in Appendix 4.A.2.

[80]One of the earliest input-output tables available that indicate this is indeed the case is the German table for 1936 (see Fremdling and Staeglin, 2014).

parameters to target today's tradable sector share (i.e. the share of tradable value added in total value added of 16% for the H region, and 24% for the F region, as opposed to 47% and 40% during the early 20th century. This corresponds to the U.K. statistics for 2011).[81]

Table 4.22 panel B displays the results of the counterfactual analysis (see Section 6 for a detailed description of the counterfactual exercise). The results for the extended model are similar to the results for the baseline model. Nominal flexibility remains the most important explanation for the benign adjustment experience under the GS. Migration- and monetary policy played smaller roles.

Norway

Besides Sweden, another country which experienced large emigration flows in the late 19th century is Norway. It is thus interesting to see how important the migration channel was for this country. Because we have no immigration series for Norway we replace the net-immigration/population ratio with the emigration/population ratio among the observables. The thus estimated model produces counterfactual volatilities that are broadly in line with those of from other countries' models (see Table 4.22 panel C). Price flexibility again is the most important contributor to per capita output stability.

France

Similarly to the central bank of Belgium, the central bank of France is known for having pushed the limits of monetary policy independence under the Gold Standard (Eichengreen and Flandreau, 2014; Bazot, Bordo and Monnet, 2014). We therefore also estimated the model with France as the H-region, and all other GS economies as the F-region. Unfortunately, there does not exist an uninterrupted immigration series for France between 1880 and 1913. Among the observables for model estimation we thus replaced the net-immigration/population series with the emigration/population series.

Table 4.22 panel D displays the counterfactual simulation results for France. Price flexibility again is the most influential factor when it comes to output stability.

[81] While the H value is based on the U.K. input-output table for 2011, the F value is an average for Germany and Sweden. All input-output tables are from OECD Statistics.

Table 4.22: *Counterfactual volatility*

		Baseline model	Rigid prices	No migration	No independence	No migration, given rigid prices	No independence, given rigid prices
		(1)	(2)	(3)	(4)	(3∣2)	(4∣2)
Panel A: United Kingdom hybrid							
y_t^p	Per capita output	1.72	3.16	1.71	1.78	3.17	3.51
			(83.67%)	(-0.76%)	(3.55%)	(0.31%)	(11.00%)
Panel B: United Kingdom extended							
y_t^p	Per capita output	1.95	3.67	1.95	2.03	3.76	4.10
			(88.23%)	(-0.07%)	(4.19%)	(2.45%)	(11.94%)
Panel C: Norway							
y_t^p	Per capita output	1.57	4.31	1.55	1.56	4.32	4.32
			(175.09%)	(-1.25%)	(-0.17%)	(0.17%)	(0.33%)
Panel D: France							
y_t^p	Per capita output	2.84	4.57	2.84	2.82	4.56	4.62
			(60.89%)	(-0.12%)	(-0.58%)	(-0.26%)	(1.06%)

Notes: Percentage change in counterfactual S.D. relative to baseline S.D. in parenthesis. Rigid prices – model with rigid prices. No migration – model without migration. No independence – model without policy independence for central bank.

Chapter 5

Spotting the Danger Zone: Forecasting Financial Crises with Classification Tree Ensembles and Many Predictors

5.1. Introduction

The number of institutions whose explicit goal is to identify and address risks to the financial system has increased in the post-2008 economic policy landscape. In the US for example, the Financial Stability Oversight Council (FSOC) has been given a statutory mandate to 'identify[] risks and respond[] to emerging threats to financial stability".[1] A core question policy makers in these institutions face is: where is the economy currently operating relative to the economic danger zones from which banking crises emanate? It is here that formal early-warning systems can make a valuable contribution.

This paper introduces classification tree ensembles (CTEs) (Breiman, 1996*a*, 2001) to financial crisis forecasting and analyzes their ability in making out-of-sample predictions for binary banking crisis indicators on the basis of several datasets: One long run annual dataset (1870-2011), covering 17 developed countries, and two post-1970 datasets – the first covering 162 countries annually and the second quarterly. The results suggest that the out-of-sample forecasting performance of CTEs substantially surpasses current best-practice logit specifications. To give a concrete example of the trade-offs involved, the favorite CTE allows policy makers to correctly forecast about 50% of banking crises, at the cost of a 5% chance of wrongly forecasting a crisis when none will actually occur. The best-practice logit specification can achieve the same 50% rate of correct crisis forecasts only at the substantially higher cost of a 25% chance of making a wrong crisis call. If policy makers prefer a higher rate of correct crisis forecasting, both prior models offer one. The CTE can correctly forecast about 90% of banking crises, with a 30% probability of making a false crisis prediction. The best-practice

[1]The citation is taken from the FSOC's website: `http://www.treasury.gov/initiatives/fsoc/Pages/home.aspx`

logit specification can achieve the same 90% rate of correctly forecasting a crisis, only at the far higher cost of an 80% chance of erroneously predicting a crisis. In both scenarios, the CTE offers the better trade-off. In light of their superior performance, CTE forecasts should become an important tool of macroprudential policy.

This paper relates to the existent literature in the following ways: It adds to the modern literature on early-warning systems (EWS) for banking crises, which was pioneered by Kaminsky (1998) and Kaminsky and Reinhart (1999) in the wake of the 1997 Southeast Asian crises. More recent contributions that analyze the predictability of banking crises in developed economies in the long-run (since 1870) are: Schularick and Taylor (2012) and Jordà (2014), while others rely on post-1970 samples covering more countries (see Drehmann and Juselius, 2012; Drehmann, 2013). This literature has shown that already relatively simple model structures, based on few predictors – most notably credit aggregates – can convey valuable information on the imminence of a banking crisis. This paper will explore whether more complex classification tree structures, based on many predictors can improve upon this.

Thus, this paper is related to the literature on economic forecasts based on many predictors (see Stock and Watson, 2002, 2006), which has stressed the possibility of improving forecasts by drawing from a large set of indicators. It will be demonstrated that increasing the number of predictors that are used in best practice early-warning systems from 7-10 to ca. 70-80, will markedly improve forecasts. The literature on economic forecasts based on many predictors has focused largely on factor modelling and prestep-dimensionality reduction techniques. Such approaches do not easily lend themselves to banking crisis-forecasting. First, most banking crisis indicators are binary 0-1 dummies that require discrete classification techniques.[2] Furthermore, widely held beliefs on the genesis of banking crises, namely that they are characterized by discontinuous threshold effects and nonlinear interaction effects between several risk factors (see Duttagupta and Cashin, 2011), are more naturally accommodated by methods which dispense with linearity assumptions from the outset. This paper will apply classification tree structures (see Breiman et al., 1984) which naturally accommodate discontinuous threshold effects as well as nonlinear interactions and can harness many predictors in doing so (also see Varian, 2014).

A classification tree can be seen as a recursive version of the more familiar signals approach to crisis forecasting. Similar to the signals approach, classification trees split a sample into two parts by searching for a predictor and a threshold along that predictor which separates the crisis observations in the sample from the non-crisis observations. Credit growth in the 90th percentile, for example, might be indicative of an impending banking crisis. After the sample has been split in two by the first threshold, the procedure is repeated for the two resulting subsamples – containing observations above and below the 90th percentile credit growth-threshold, respectively. In this way a sample can be recursively partitioned into crisis

[2]Exceptions are continuous crisis indices such as the exchange market pressure index pioneered by Eichengreen, Rose and Wyplosz (1994). Such indices are available for fewer countries and cover shorter time-spans than their binary counterparts.

and non-crisis subsamples.[3] Individual classification trees however are renowned for being highly unstable, i.e. their high variance in mean-squared-error terms. This instability severely impairs their forecasting ability. To overcome this, Breiman (1996*a*) has suggested to estimate many trees on many bootstrap samples and then aggregate them into a classification tree ensemble – or forest. This so-called bagging (short-hand for bootstrap aggregating) takes high-variance trees and combines them into low-variance forests, which retain the ability of individual trees to deal with many predictors and accommodate nonlinear threshold- and interaction effects. Their ability to thus precisely delineate several danger zones, *and* their ability to harness many predictors in doing so, has already made them a mainstay in other research areas, such as genetics, where often thousands of genetic markers are analyzed with respect to their contributions to particular diseases (e.g. Díaz-Uriarte and De Andres, 2006). Further examples for the wide applicability of tree-based ensemble methods come from ecology (e.g. Prasad, Iverson and Liaw, 2006), bioinformatics (e.g. Chen and Liu, 2005) and high energy particle physics (Albert et al., 2008). In parallel work, Alessi and Detken (2014) have also recently investigated the potential of CTEs for banking crisis forecasting.[4]

This paper is structured as follows: Section 5.2 provides an introduction to classification tree-ensembles and section 5.3 introduces the datasets. These datasets form the basis for the out-of-sample forecasting contest between CTEs and the best-practice logit specifications in section 5.4. Section 5.5 concludes this paper by showing how a particular CTE, random forest, would have fared in forecasting the 2007/2008 financial crisis.

5.2. Methodology: Classification Tree Ensembles

This section gives an introduction to classification trees and their ensembles (CTEs). It also contrasts the classification tree-approach with the generalized linear models (GLM) framework, in order to clarify how classification trees differ from logit and probit models – the backbone of many current EWS's for banking crises.

5.2.1. Single Classification Trees

Classification trees separate crisis- from non-crisis observations according to a set of discrete threshold rules. For instance, if an economy's private sector indebtedness exceeds a certain threshold, and GDP growth is faltering below another threshold, a classification tree might

[3] Recent contributions have already begun to explore the potential of classification trees for the analysis of banking crises (Davis and Karim (2008*a*) and Duttagupta and Cashin (2011)).

[4] Alessi and Detken (2014)'s approach differs considerably from the approach followed here. They use a tree ensemble to identify important variables, and then estimate a single tree based off these variables. Single tree forecasts allow for a better interpretation than ensemble based forecasts. However, single tree forecasts are plagued by high variance and thus are unlikely to be precise. Furthermore, identifying important variables with a CTE is problematic: Several methods exist to determine the importance of a predictor in a CTE – they can produce very different results (see the series of papers published in BMC Bioinformatics: Nicodemus, Wang and Shugart (2007), Strobl et al. (2007), Strobl et al. (2008), Nicodemus and Malley (2009) and Nicodemus et al. (2010)).

categorize the observation into the high risk category. If on the other hand, indebtedness was lower and GDP growth were higher, the observation might be categorized as low risk.

Figure 5.1 illustrates this idea graphically. x_1 and x_2 are two predictors conveying information about financial crisis risk. In the two-dimensional predictor space spanned by x_1 and x_2 black dots indicate crisis observations, while white dots stand for non-crisis observations. A classification tree is characterized by a partition of the predictor space into M non-overlapping regions R_m and an associated set of crisis-probabilities p_m ($m = 1, ..., M$). The regions are estimated through recursive partitioning – a step-wise algorithm. The algorithm will be described in more detail in the following section, but a short description is given here in order to provide an intuition for how the region estimates $\widehat{R}_m$ come about: Recursive partitioning searches across predictors for a threshold that separates crisis from non-crisis observations (see upper left panel of figure 5.1). Next, the sample splitting continues on the obtained subsamples as indicated by the upper right and lower left panels of figure 5.1. Once recursive partitioning stops a crisis probability $\widehat{p}_m$ for region $\widehat{R}_m$ ($m = 1, ..., M$) is estimated according to the fraction of crisis observations in that region:

$$\widehat{p}_m = \frac{\sum_{i \in \widehat{R}_m} y_i}{\sum_{i \in \widehat{R}_m} 1}, \tag{5.1}$$

where $y_i = 1$ if a crisis occurs within the next two years, and $y_i = 0$ in all other cases. In the final partition depicted by the lower left panel of figure 5.1 for instance, regions 3 and 5 delineate danger zones of high crisis risk. Regions 1 to 3, conversely, predict 0 crisis risk. The partitioning of the predictor space can also be represented as a dendrogram, in which the final nodes correspond to the final region estimates – hence the name classification *tree* (see lower right panel of figure 5.1).

Formally, a classification tree predicts crisis probability as

$$\widehat{\mathcal{T}}(X_i) = \sum_{m=1}^{M} \widehat{p}_m I(X_i \in \widehat{R}_m), \tag{5.2}$$

where $\widehat{p}_m$ is the probability estimate of a crisis occurring within the following 2 years, X_i is a $J \times 1$ vector of predictor values, for observations $i = 1, ..., N$ and $I(X_i \in \widehat{R}_m)$ is an indicator function that equals 1 when region $\widehat{R}_m$ contains observation i.

A comparison to current workhorse specifications for banking crisis EWS, such as logit and probit models, will help to put the characteristics of classification trees into sharper contrast. In the specification of a generalized linear model (GLM) with a binomially distributed dependent variable

$$P(y_i|X_i) = g^{-1}(X_i'\beta) \tag{5.3}$$

a dual set of assumption is made: First, in the form of a link function g (e.g. the logit link), whose inverse – the mean function – maps the linear predictor $X_i'\beta$ onto the $[0, 1]$-range.

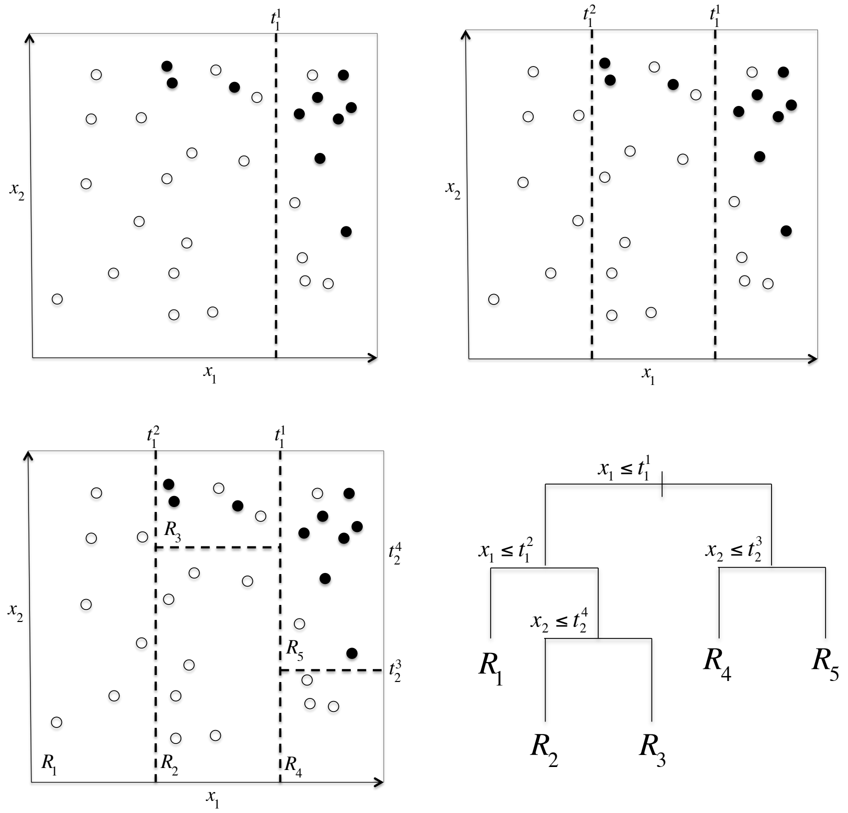


Figure 5.1: *Recursive Partitioning: An Illustration*

Notes: The upper left panel shows the first recursive partitioning step, while the upper right panel shows the second recursive partitioning step. The lower left panel shows a third and fourth partitioning step. The lower right panel shows the tree corresponding to the partition in the lower left panel. Filled circles (Crisis); empty circles (No crisis). x_j predictors. t_j^s splits/thresholds. R_m terminal regions.

Second, by assuming that the predictor values enter crisis risk only as a linear additive combination $X_i'\beta$.[5]

An advantage of classification trees is that they are more flexible in both regards. First, the nonparametric calculation of crisis probabilities according to (5.1) obviates the need to map an unbounded predictor range to the $[0, 1]$-crisis probability domain with the help of a particular mean function. Classification trees are thus free to approximate a multitude of functional forms between the dependent variable and the predictors through the combination of discrete thresholding rules.[6] Secondly, contrary to the GLM framework, classification trees are geared towards identifying nonlinear and discontinuous predictor interactions, while

[5]There exists however the possibility to explicitly define some interaction effects and higher order terms and include them among the other predictors.

[6]The right sort and degree of functional flexibility depends on the problem at hand. Liu, Bowyer and Hall (2004) present a set of conditions under which classification trees outperform artificial neural networks although the latter are generaly more flexible; the financial crisis forecasting problem seems to fit this set of conditions.

maintaining the ability to also approximate smooth and even linear relationships.[7] A downside of this flexibility is that globally optimal estimation of all the parameters that characterize a classification tree $\Theta = \{R_m, p_m\}_{m=1}^{M}$ constitutes a NP-complete problem (Hyafil and Rivest, 1976). Thus classification tree regions are typically estimated through recursive partitioning – a greedy search algorithm that conducts a step-wise locally optimal estimation.

5.2.2. Recursive partitioning

At each recursive partitioning step a thresholds, or split point, is selected in order to minimize a loss function. This loss function is the (negative) information gain $\mathcal{IG}$, which measures the extent to which a split point is successful in separating crisis from non-crisis observations. Evaluating the homogeneity of a region in terms of the crisis and non-crisis observations contained in it necessitates the definition of a measure of region impurity. Gini impurity – a parabolic function of the proportion of crisis observations p_a in region R_a – is such a measure:

$$\mathcal{GI} = -2p_a^2 + 2p_a,$$

$\mathcal{GI}$ reaches minima of 0 in regions that contain only crisis observations ($p_a = 1$) or only non-crisis observations ($p_a = 0$). For $0 < p_a < 1$ $\mathcal{GI}$ exceeds 0 and reaches a maximum of 0.5 for regions that contain an equal amount of crisis and non-crisis observations ($p_a = 0.5$). As its name suggests, gini impurity is thus a measure of region impurity that penalizes the mixing of crisis and non-crisis observations within a region. On the basis of this measure it is possible to define the loss function according to which split points are selected at each recursive partitioning step – the information gain:

$$\mathcal{IG}(R_a, R_b) = \mathcal{GI}(R_a \cup R_b) - 0.5[\mathcal{GI}(R_a) + \mathcal{GI}(R_b)]$$

$\mathcal{IG}(R_a, R_b)$ compares the gini impurity of a parent region $\mathcal{GI}(R_a \cup R_b)$ with the average gini impurity of the two child regions $\mathcal{GI}(R_a)$ and $\mathcal{GI}(R_b)$ that a split point creates. The negative $\mathcal{IG}$ constitutes the loss function that is minimized at each recursive partitioning step $s = 2, ..., S$ through the choice of a splitting predictor j and a split point t along the range of that splitting predictor:

$$\hat{t}_j^s = \arg\max_{t_j^s} \mathcal{IG}\left(R_a^s(t_j^s|\hat{t}_j^1, ..., \hat{t}_j^{s-1}), R_b^s(t_j^s|\hat{t}_j^1, ..., \hat{t}_j^{s-1})\right) \tag{5.4}$$

[7] To see this, imagine crisis and non-crisis observations were separated along one of the two linear diagonals in the panels of figure 5.1. In this case, a good separation of crisis from non-crisis observations would necessitate the estimation of several more regions, but eventually a satisfying approximation to the diagonal separation could be achieved through a somewhat more finely granulated partitioning of the predictor space. Note, however, that smaller regions tend to contain fewer observations and the corresponding crisis probability estimates would be less precise.

The thrust behind (5.4) is to estimate thresholds that separate crisis and non-crisis observations into different regions.[8] Note that only the first split $s = 1$ is an unconditional one; all others depend on all previously estimated splits $\hat{t}_j^1, ..., \hat{t}_j^{s-1}$.

Recursive partitioning can end in two ways: either running its course until the classification tree has been "fully grown", i.e. only pure regions are left, or recursive partitioning can be ended through an ad hoc stopping rule. For example, each terminal region can be required to contain a minimum number of observations.[9] The final partition constitutes an estimate of the M terminal regions $\{\widehat{R}_m\}_{m=1}^M$, on the basis of which the classification tree (5.2) can be completed by estimating crisis probabilities $\{\widehat{p}_m\}_{m=1}^M$ according to (5.1). Algorithm box 1 gives an overview of all the steps involved in estimating a classification tree.

Despite their ability to handle many predictors and accommodate nonlinear threshold- and interaction effects, classification trees have been associated with poor out-of-sample forecasts of banking crises (see Davis and Karim, 2008*a*). What is the reason for this? The most significant constraint that holds back the forecasting performance of a single classification tree is its high variance – an unwelcome side-effect of recursive partitioning. Small changes in the sample under analysis can easily lead to changes in the early partitions and, due to the dependence of later on earlier partitions, this change then reverberates throughout the tree. The results in section 5.4 will confirm that this instability deals a severe blow to the forecasting performance of single classification trees. Fortunately, as explained in the next section, combining many classification trees into a CTE can provide a solution to this problem.

Algorithm 1 Classification Tree Pseudocode

1. Estimate regions $\{R_m\}_{m=1}^M$ through recursive partitioning:
repeat ▷ Recursive Partitioning
    Select splitting predictor and split point according to (5.4).
until Stopping rule applies
⇒ Region estimates $\{\widehat{R}_m\}_{m=1}^M$:

2. Estimate crisis probabilities $\{p_m\}_{m=1}^M$ according to (5.1).
⇒ Classification Tree $\widehat{\mathcal{T}}(X_i) = \sum_{m=1}^M \widehat{p}_m I(X_i \in \widehat{R}_m)$

Notes: The pseudocode shows the steps involved in generating a single classification tree.

[8] Note that the step-wise estimation through recursive partitioning allows classification trees to make use of many predictors, whereas generalized linear models estimated through maximum likelihood, would run into problems associated with the curse of dimensionality.

[9] Usually the application of such an ad hoc stopping rule is necessary to avoid poor out-of-sample predictions due to severe in-sample overfitting. The following analyses impose a lower bound of 10 observations on the terminal region size of single classification trees. The single tree results are however, robust to variations in the stopping rule.

5.2.3. Classification tree ensembles

As the name suggests an ensemble of trees – or forest $\mathcal{F}$ – consists of many classification trees $\mathcal{T}_b$, $b = 1, ..., B$. Each individual tree "grows" on an i.i.d. bootstrap-sample X^b, for which N observations are drawn with replacement from the original data X. Such bootstrapping with subsequent aggregation is referred to as bagging (Breiman, 1996*a*).[10] If each tree is given the same weight, a forest's crisis probability estimate is

$$\widehat{\mathcal{F}}(X_i) = \frac{1}{B}\sum_{b=1}^{B}\widehat{\mathcal{T}}_b(X_i), \tag{5.5}$$

Thus the forest's prediction is simply the average prediction of the B single trees.[11]

Why are tree ensembles expected to have better predictive ability than individual classification trees? Consider the variance-bias decomposition of the mean squared error (MSE) of a tree[12]

$$E\left[(y - \widehat{T}_b)^2\right] = \underbrace{E\left\{\left[\widehat{T}_b - E(\widehat{T}_b)\right]^2\right\}}_{:=\sigma^2_{tree}} + \underbrace{\left[E(\widehat{T}_b) - y\right]^2}_{:=bias^2_{tree}},$$

and a forest

$$E\left[(y - \widehat{F})^2\right] = \underbrace{E\left\{\left[\widehat{F} - E(\widehat{F})\right]^2\right\}}_{:=\sigma^2_{bag}} + \underbrace{\left[E(\widehat{F}) - y\right]^2}_{:=bias^2_{bag}}.$$

The main rationale behind bagging is its variance-reducing effect: The variance of the average of B identically – but not independently – distributed variables (note that trees are grown on overlapping bootstrap samples) is:

$$\sigma^2_{bag} = \rho\sigma^2_{tree} + \frac{1-\rho}{B}\sigma^2_{tree},$$

where ρ is the pairwise correlation between any two trees[13] and thus

$$\sigma^2_{bag} \leq \sigma^2_{tree}.$$

[10]Note that the use of the bootstrap methodology in bagging is somewhat unusual, in that it is not used for statistical inference here. Hence the choice of the i.i.d. boostrap is harmless at the bagging stage. However, temporal and cross-sectional dependencies in the data presumably resurface later in the form of temporally and cross-sectionally dependent crisis probability estimates. Therefore at a later stage, for the evaluation and comparison of the models' predictive ability on the basis of their crisis probability estimates, block-bootstrap procedures become important for robustifying confidence intervals and statistical tests (see appendix).

[11]CTEs appear to be rather unaffected by tree growth stopping rules (Segal, 2004). Fully growing each tree in an ensemble has consequently established itself as a standard and has therefore been applied to the following analysis.

[12]For ease of clarification, the following argument assumes fixed predictors and thus abstracts from population MSE, which is in any case beyond the control of forecasters.

[13]Note the exchangeability assumption needed in the derivation of this expression: $Cov(T_i, T_j) = Cov(T_1, T_2)$ for any $i \neq j$.

Hence the variance of a tree ensemble can generally be expected to be lower than the variance of an individual tree (see Bühlmann and Yu, 2002; Buja and Stuetzle, 2006), with $\rho\sigma^2_{tree}$ constituting the lower bound on variance that can be reached through bagging.

One of the most prominent ensemble algorithms that will be investigated in the following sections is random forest (Breiman, 2001), which aims at lowering ensemble variance σ^2_{bag} even further, by lowering ρ – or the correlation between trees. This is done by considering only a random subset J_{try} of all J predictors in the maximization problem faced at each recursive partitioning step (5.4). This subset of predictors is drawn without replacement from the set of all predictors.[14] Individual trees thus no longer vary only with respect to the bootstrap sample on which they are "grown", but also with respect to the selection of splitting predictors. The trees become less similar (i.e. ρ is lower) and all else equal, ensemble variance decreases.[15] Besides this, random forest equals bagging,

$$\widehat{\mathcal{RF}}(X_i) = \frac{1}{B}\sum_{b=1}^{B}\widehat{\mathcal{T}_b^{RF}}(X_i). \tag{5.6}$$

A concise overview of all the steps involved in obtaining the bagging- (5.5) and random forest crisis probabilities (5.6) can be found in algorithm box (2).

Note that while the branches and leaves of an individual tree can still be traced and interpreted in economic terms, one drawback of CTEs is that they lose this straightforward interpretability. In this sense CTE-based forecasts might be thought of as a complement to methodologies that are better suited for the evaluation of the relative importance of different risk factors.[16]

[14] A widely used default choice for J_{try}, which the following analysis will adhere to is $\lfloor\sqrt{J}\rfloor$ (see Breiman, 2002). Generally, the paper makes use of default settings sourced from the literature for fine-tuning parameters (J_{try} and tree growth stopping rules). Given the rarity of severe banking crises setting aside part of the data for tuning considerations (i.e. validation data) is an excessive strain on the samples.

[15] Bagging and randomization also have countervailing effects on prediction bias. Averaging across many trees smoothens out the discontinuities found in any single tree. This can lower CTE-bias (Buja and Stuetzle, 2006). However, each bootstrap sample leaves out $\approx 37\%$ of observations, which increases finite sample bias compared to larger resamples.

[16] Although several methods exist to determine the importance of a predictor in a CTE, for the applications that follow I find few commonalities between the predictor rankings produced by two of the most common variable importance measures (see appendix for results and further discussion).

Algorithm 2 Random Forest Pseudocode

for $b = 1$ to B **do** ▷ Estimate B Classification Trees

1. Draw i.i.d. bootstrap sample X^b of size N (with replacement).

2. Estimate regions $\{R_m^b\}_{m=1}^M$ through recursive partitioning:

repeat ▷ Recursive Partitioning

a) Draw J_{try} predictors (without replacement).

b) Select splitting predictor and split point according to (5.4).

until Stopping rule applies (i.e. trees are fully grown)

$\Rightarrow$ Region estimates $\{\widehat{R}_m^b\}_{m=1}^M$:

3. Estimate crisis probabilities $\{p_m^b\}_{m=1}^M$ according to (5.1).

$\Rightarrow$ Classification Tree $\widehat{\mathcal{T}_b^{RF}}(X_i) = \sum_{m=1}^M \widehat{p}_m^b I(X_i \in \widehat{R}_m^b)$

end for

$\Rightarrow$ B Classification Trees $\{\widehat{\mathcal{T}_b^{RF}}(X_i)\}_{b=1}^B$

$\Rightarrow$ Random Forest $\widehat{\mathcal{RF}}(X_i) = \frac{1}{B}\sum_{b=1}^{B} \widehat{\mathcal{T}_b^{RF}}(X_i)$ ▷ Generate Ensemble

Notes: The pseudocode shows the steps involved in generating the $\mathcal{RF}$-ensemble (5.6). This pseudocode also covers the generation of the $\mathcal{F}$-ensemble (5.5) if the number of randomly drawn predictors J_{try} in step 2. a) is set equal to the total number of predictors J. In this case, the $\mathcal{F}$- and the $\mathcal{RF}$-ensembles become equal.

5.3. Data

This section introduces three datasets on the basis of which I will evaluate the forecasting performance of logit models, single classification trees and CTEs. Systemic banking crises are rare. Their statistical analysis necessitates datasets, which cover large time spans or many countries – one usually comes at the cost of the other. Therefore I make use of one long-run sample spanning from 1870 to 2011, as well as two post-1970 samples with broader country coverage.

5.3.1. The Long-Run Sample, 1870-2011

With regard to the long-run sample, this study utilizes the dataset introduced by Schularick and Taylor (2012). After further extensions by Jordà, Schularick and Taylor (2013), this dataset now ranges from 1870 to 2011 and covers 17 countries. Usually, these countries cumulatively constitute more than half of the world's GDP (according to Maddison GDP estimates).

The dataset features macroeconomic indicators (GDP, consumption, investment, consumer prices, the current account and exchange rates) as well as financial indicators (bank loans, total bank assets, stock prices, interest rates, public debt and monetary aggregates). These are the base indicators from which ca. 70 predictors are derived (see table A1 in the data appendix). The bare nominal series (n) are utilized when they are deemed to be of interest with respect to crisis risk (e.g. nominal interest rates). CPI-deflated quantities, growth rates (gr), trend

Table 5.1: *Datasets*

Dataset	Long-run 1870-2011 sample	Broad post-1970 sample I	Broad post-1970 sample II
Base indicators	Schularick and Taylor (2012)	IFS, PWT, Abbas et al. (2013)	IFS, Datastream
Crisis dummy	Schularick and Taylor (2012)	Laeven and Valencia (2013)	Laeven and Valencia (2013)
Frequency	annual	annual	quarterly
Time Span	1870 - 2011	1970 - 2011	1970 - 2011
# of countries	17	162	162
# of predictors	77 (Table A1)	70 (Table A2)	73 (Table A3)
# of crises	93	147	147
N	2414	7081	30967

Notes: *N* number observations. IFS International Financial Statistics. PWT Penn World Tables. The Schularick and Taylor (2012) dataset has subsequently been extended and updated (see Jordà, Schularick and Taylor, 2013). All three datasets are unbalanced. The number of observations and crises will vary across applications.

deviations (gap), to GDP ratios (/GDP), global (GDP-weighted) averages (glo), real exchange rates and interest rate differentials are also obtained (see Alessi and Detken, 2011, for a similar approach). Furthermore, to obtain an even more detailed snapshot of economic conditions several of these transformations are combined when it makes economic sense, for example, the gap of the loans to GDP ratio (Loans/GDP (gap)). Schularick and Taylor (2012) also provide a binary banking crisis indicator, the definition of which follows Laeven and Valencia (2008): The indicator takes a value of 1 for years characterized by bank runs, a jump in default rates and large capital losses associated with public interventions as well as bankruptcies or forced mergers of major financial institutions. Otherwise the indicator takes a value of 0. Overall, the dataset contains 93 systemic banking crises (for the country-year incidence of crises see the crisis map, figure A1, in the data appendix).

5.3.2. The Broad Post-1970 Samples

For the post-1970 period, this paper makes use of the binary banking crisis indicator provided by Laeven and Valencia (2013). This indicator encompasses 162 countries and 147 systemic banking crises between the years of 1970 and 2011 (for the country-year incidence of crises see the crisis map, figure A2, in the data appendix).[17]

Next, annual and quarterly base indicators from the IMF IFS-database and Datastream were obtained. When selecting base indicators, it was paramount to consider their availability across a wide range of countries, as a multitude of missing values would further endanger the already small number of financial crises. The annual indicators include consumer prices, net exports, exchange rates, bank loans, stock prices, interest rates and public debt (provided by

[17]For the quarterly dataset, the quarterly crisis dummy was set to 1 for all quarters, if the year dummy was 1. This is also the case if a financial crisis began later in the year.

Abbas et al., 2013). The quarterly indicators include GDP, consumer prices, exchange rates, bank loans, stock prices, house prices, interest rates, foreign liabilities and reserves. For the post-1970 annual sample, further use is made of the GDP-, consumption- and investment-series from the Penn World Tables (Feenstra, Inklaar and Timmer, 2013), as well as the public debt to GDP ratios from Abbas et al. (2013). A detailed list of all the predictors can be found in the data appendix (see tables A2 and A3). An overview of the characteristics of all datasets is given in table 5.1.

5.4. Performance Comparison

This section stages the competition between logit models, single classification trees and CTEs. The rules are simple: the method whose crisis-probability predictions achieve the highest out-of-sample area under the receiver operating characteristic curve (AUC) wins.[18] The following paragraph gives a short introduction to the AUC measure:

Each crisis forecasting model faces a true positive rate (TPR) – false positive rate (FPR) trade-off. At one extreme, the model could make a crisis call for each period, thus correctly predicting all crises (100% TPR). However, this comes at the price of never correctly giving the all-clear (100% FPR). At the other extreme, a model could never issue a crisis warning, and thus be correct for all non-crisis periods (0% FPR) at the cost of never correctly predicting a crisis (0% TPR). Crisis probability estimates can be translated into crisis-calls or all-clears depending on whether crisis probability passes a certain threshold $\eta \in [0, 1]$. For different thresholds different TPR-FPR combinations are obtained. By slowly shifting the threshold η from 0 to 1 all of the TPR-FPR combinations that a model is capable of can be depicted in the TPF-FPR plane (a unit square). The resulting curve is the receiver operating characteristic (ROC) curve, which gives a comprehensive description of a model's predictive ability. The area under this curve (AUC) is a slightly more aggregate measure, which most of the following model comparisons will be based on. The AUC ranges from 0.5 to 1. An AUC of 1 indicates a perfect EWS, which correctly forecasts all crises as crises, and all non-crises as non-crises. An AUC of 0.5 indicates an entirely uninformative EWS. The corresponding ROC curve is a diagonal in the TPR-FPR plane: a higher TPR only comes at the cost of an equally higher FPR. Intuitively, the AUC represents the probability that for a randomly selected pair of one crisis and one non-crisis observation, the crisis probability estimate for the crisis-observation is higher than that for the non-crisis observation. For a comprehensive introduction to the ROC curve and the AUC in the context of financial crisis forecasting see Jordà (2014).

All model evaluations are based on out-of-sample data. For the CTEs, so-called out-of-bag (OOB) data is used (see Breiman, 1996*b*). A tree's OOB data are those $\approx$ 37% of observations that are not contained in the bootstrap sample on which this tree was estimated.

[18]The receiver operating characteristic (ROC) curve and the AUC are useful for the evaluation of predictive performance in classification problems where one class constitutes a minority class (e.g. banking crises). Under such circumstances, many other criteria tend to inflate the predictive ability of models that blindly predict the majority class.

Correspondingly, each observation constitutes OOB data to $\approx 37\%$ of the trees in an ensemble. Out-of-sample crisis probability estimates are obtained by evaluating each observation by only those trees in an ensemble for which it constitutes OOB data. For single classification trees and the logit models, this section conducts Monte Carlo Cross-Validation (MCCV) evaluations that are comparable to the OOB evaluations. For instance 100 logit models are estimated based upon 100 bootstrap samples (drawn with replacement). With the observations not contained in the bootstrap samples 100 out-of-sample AUCs are calculated and their average constitutes the MCCV estimate. The MCCV-AUC is comparable to the OOB-AUC in that both are estimates of expected out-of-sample performance ($AUC = E(AUC_{\mathcal{T}})$) as opposed to conditional out-of-sample performance – i.e. performance conditional on a particular training dataset $\mathcal{T}(AUC_{\mathcal{T}})$ (see Haste, Tibshirani and Friedman, 2013, pp.254-257).

5.4.1. Logit EWS

To obtain a yardstick against which to measure the performance of CTEs this subsection first reports logistic regression-based results. Bi- and multivariate logit models were estimated on the basis of a selection of predictors, which are comparable to those found in the literature.

Among the single predictors the largest AUCs come from the private burden (AUC=.64) and the loans/GDP gap (AUC=0.63). They are significantly different from 0.5 at the 1% significance level.[19] The public debt/GDP gap (AUC=0.59) and the public burden (AUC=0.58) achieve significance at higher levels. Most of the other AUC estimates hover closely above 0.5 – a rather poor result. Generally, these results are similar to the ones obtained by Jordà (2014) who, based on comparable specifications, reports AUCs ranging from 0.52 to 0.67.[20]

Next are multivariate specifications. The variable selections are displayed on the right half of table 5.2. They are inspired by similar specifications in Schularick and Taylor (2012) and Jordà, Schularick and Taylor (2011). AUCs of all three multivariate models are significantly different from 0.5 at the 1% significance level. They range from 0.62 to 0.65.

[19] The reported results hold up when confidence bands and tests are robustified against serial and cross-sectional correlation in the crisis probability estimates (see appendix).

[20] On the basis of 19 systemic crises (11 of which are associated with the most recent global financial crisis) Drehmann and Juselius (2013) report mean AUC estimates between 0.8 and 0.9 for their logit specifications. These high AUC estimates may hint at important country- and time specificities in the development of financial crises. The soon to be introduced CTEs also enter the 0.8-0.9 range of AUC estimates, but on the basis of a more diverse set of banking crises (≥ 70). This will allow forecasters to predict banking crises, which resemble crises from the more distant past or crises from less similar countries.

Table 5.2: *Logit-EWS*

	Results		
	AUC	95%-CI	N
Bivariate			
Loans/GDP (gap)	0.63 * *	[0.55,0.71]	1283
Public Debt/GDP (gap)	0.58 *	[0.51,0.66]	1347
Narrow Money/GDP (gap)	0.55	[0.48,0.63]	1308
LT Interest Rate	0.52	[0.45,0.6]	1425
GDP (gr)	0.52	[0.44,0.6]	1402
Inflation	0.54	[0.47,0.61]	1492
Exchange Rate (gap)	0.51	[0.44,0.59]	1502
Public Burden	0.57 †	[0.5,0.65]	1321
Private Burden	0.64 * *	[0.56,0.72]	1223
Joint Burden	0.52	[0.44,0.61]	1180
Multivariate			
Baseline	0.62 * *	[0.55,0.7]	1144
IA	0.65 * *	[0.57,0.73]	1144
FE & IA	0.65 * *	[0.57,0.73]	1144

	Specification		
	Baseline	IA	FE & IA
Variables			
Loans/GDP (gap)	✓	✓	✓
Public Debt/GDP (gap)	✓	✓	✓
Narrow Money/GDP (gap)	✓	✓	✓
LT Interest Rate	✓	✓	✓
GDP (gr)	✓	✓	✓
Inflation	✓	✓	✓
Exchange Rate (gap)	✓	✓	✓
Interaction Terms			
Public Burden		✓	✓
Private Burden		✓	✓
Joint Burden		✓	✓
Loans/GDP x GDP (gr)		✓	✓
Public Debt/GDP x GDP (gr)		✓	✓
Loans/GDP (gap) x Exchange Rate (gap)		✓	✓
Fixed Effects			
Country-FE			✓

Notes: Dependent variable: two-year horizon before crisis. Out-of-sample *AUC*- and confidence band estimates are based on Monte Carlo Cross-Validation (see Picard and Cook, 1984; Arlot, Celisse et al., 2010): 100 MC-draws of training (63,2%) - test (36,8%) data partitions. IA interaction terms; FE country fixed effects; N number of training observations (= 0.632×total number of observations). † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Compared to the baseline specification, the IA specification with interaction terms is successful in conveying extra information on the imminence of a banking crisis (AUC=0.65). The AUC remains the same after the additional inclusion of country-fixed effects. These results are very close to the out-of-sample results reported by Schularick and Taylor (2012) (AUC=0.646), which are based on similar logit specifications and data.

5.4.2. Classification Tree-based EWS

CTEs are not just an ensemble of trees but also an ensemble of techniques. To obtain an impression of the relative efficacy of bagging, randomization and the use of many predictors, the following analysis will build up to the final $\mathcal{RF}$ model one step at a time. First, a single classification tree, based on the same restricted selection of ten predictors as the IA logit model was, will be presented, before bagging and randomization is added to the recipe. After that, the same three steps – i) single tree, ii) bagging, iii) randomization – will be analyzed on the basis of the broader set of 76 predictors.

5.4.2.1 Single Tree

The left hand side of table 5.3 displays results for the restricted predictor selection. Here, a single tree performs badly (AUC = 0.55). This confirms similar findings by Davis and Karim (2008*a*). When put in terms of the MSE equation (5.2.3), a likely explanation for this is the high variance of single classification trees. Estimation through recursive partitioning makes them highly susceptible to small changes in finite training samples.

5.4.2.2 Bagging

Indeed, the dramatic improvement in forecasting performance for an ensemble made up of many trees over an individual tree, appears to confirm that tree variance was to blame for an individual tree's bad performance. The second row in the upper left quadrant of table 5.3 displays the effect of bagging in the ten-variable setting. The AUC leaps by more than 0.2 to a value of 0.77. This AUC is significantly higher than that displayed by the FE & IA-logit model.

5.4.2.3 Random Forest

The third model in the upper left quadrant of table 5.3 is the $\mathcal{RF}$-estimator. The additional randomization, in form of randomly analyzing only three out of the ten predictors at each recursive partitioning step, leads to a slightly higher mean AUC estimate of 0.79. CTEs have already left behind their logistic competitors without yet having capitalized on their ability to make forecasts with far more predictors.

5.4.2.4 Many Predictors

I now turn to the more predictor-intensive contenders. The results are displayed in the upper right quadrant of table 5.3. The extension of the list of predictors to a total of 76 results in a

Table 5.3: *$\mathcal{CT}$-EWS: Long-run 1870-2012 Sample*

	Results					
	Restricted Selection			**Many Predictors**		
Model	AUC	95%-CI	N	AUC	95%-CI	N
Single Tree	0.55	[0.5,0.6]	1816	0.63 §	[0.57,0.7]	1742
Bagging	**0.77**	[0.73,0.81]	1816	**0.87** §	[0.84,0.9]	1742
Random Forest	**0.79**	[0.75,0.83]	1816	**0.88** §	[0.85,0.91]	1742
	Specification					
	Restricted Selection			**Many Predictors**		
Parameter	Single	Bagging	RF	Single	Bagging	RF
B	1	5000	5000	1	5000	5000
J_{try}	10	10	3	76	76	9
J		10			76	
# of crises		72			70	

Notes: Dependent variable: two-year horizon before crisis. Restricted Selection: Loans/GDP (gap), Public Debt/GDP (gap), Narrow Money/GDP (gap), LT Interest Rate, GDP (gr), Inflation, Exchange Rate (gap), Loans/GDP, Public Debt/GDP, LT Interest Rate (n). Many Predictors: see table A1 in the data appendix. For single tree: out-of-sample mean AUC- and confidence band estimates are based on Monte Carlo Cross-Validation (see Picard and Cook, 1984; Arlot, Celisse et al., 2010); 100 MC-draws of training (63,2%) - test (36,8%) data partitions. For ensembles: out-of-sample AUC-estimates (and confidence intervals) are based on out-of-bag (OOB)-data (see Breiman, 1996*b*). N number observations. J number of predictors under analysis. J_{try} number of predictors randomly selected and considered as a splitting variable at each recursive partitioning step. B number of trees. Specification table: If there is only a single entry in the bagging column, this means that all models share the same specification. § H_0: $AUC_{many} - AUC_{restricted} = 0$. **Bold** H_0: $AUC - AUC_{logitFE\&IA}(= 0.65) = 0$.

second significant leap in forecasting performance, by about 0.1 for the $\mathcal{F}$- (AUC=0.87) and $\mathcal{RF}$ (AUC=0.88) estimators. Even the single classification tree (AUC=0.63) now performs similarly to the multivariate logit EWS. In summation, the combination of many classification trees into an ensemble and the making use of many predictors result in marked improvements in banking crisis forecasts.

5.4.3. ROC-Comparison

Depending on how much weight policy makers put on making correct crisis calls as opposed to correct all-clears, the logit EWS might be the preferable EWS after all. To see whether this is the case, figure 5.2 displays the ROC curves of both EWS's. The $\mathcal{RF}$ model offers the higher TPR for any given FPR – equivalently the $\mathcal{RF}$ model offers a lower FPR for any given TPR. Evidently, regardless of policy-makers' preferences, the $\mathcal{RF}$ EWS offers the better TPR-FPR trade-off.

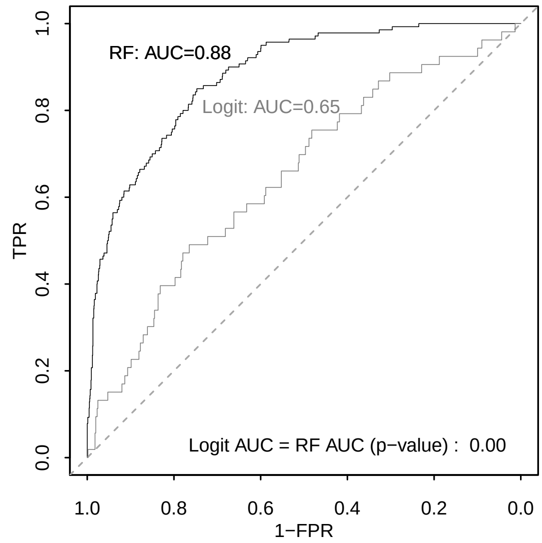


Figure 5.2: *ROC-Comparison*

Notes: Receiver Operating Characteristic curves of the logit model with country FE and interaction terms (grey) and $\mathcal{RF}$ model (black). The p-value corresponds to a test for equality of AUCs according to (DeLong, DeLong and Clarke-Pearson, 1988). TPR true positive rate. FPR false positive rate.

In order to get a better indication of $\mathcal{RF}$ EWS's performance, some of the exemplary TPR-FPR combinations from figure 5.2 should be studied. The $\mathcal{RF}$ EWS offers a balanced TPR-FPR trade-off at about $TPR = (1 - FPR) = 0.80$, i.e. it enables policy makers to correctly forecast 80% of crises and 80% of non-crises. However, if a 20% probability of mistakenly forecasting a crisis is deemed too high by policy makers, the $\mathcal{RF}$ EWS allows for a reduction of the probability of mistakenly forecasting a crisis to 5%, while still correctly forecasting about 50% of banking crises. At the other extreme, policy makers eager not to miss any crisis could use the $\mathcal{RF}$ estimator to correctly forecast 95% of crises. This will however result in only correctly predicting about 40% of non-crises. Any of these trade-offs leaves policy makers substantially better off than when using the logit EWS.

5.4.4. Robustness

In order to check whether the main results generalize, the analysis is repeated for the annual and quarterly post-1970 samples, emerging market and good quality data-subsamples, a different crisis dummy as well as 1-year and 3-year pre-crisis horizons. In an effort to save space and to counteract repetitiveness table 5.4 presents an abbreviated analysis that only reports the results for the random forest models.[21]

Concerning the 1-, 2-, and 3-year pre-crisis horizons, AUCs generally increase with the

[21]See the robustness appendix for an extended analysis of the annual and quarterly post-1970 samples.

Table 5.4: *Robustness: Various Random Forest-EWS*

	Restricted selection			**Many predictors**			
Model	AUC	95%-CI	N [crises]	AUC		95%-CI	N [crises]
			Long-run 1870-2011 dataset				
1-year horizon	0.63	[0.56,0.69]	1816 [71]	**0.79**	§	[0.73,0.85]	1742 [70]
2-year horizon	**0.79**	[0.75,0.83]	1816 [70]	**0.88**	§	[0.86,0.91]	1742 [70]
3-year horizon	**0.82**	[0.8,0.85]	1816 [69]	**0.89**	§	[0.87,0.91]	1742 [69]
RR dummy	**0.76**	[0.72,0.8]	1800 [84]	**0.86**	§	[0.83,0.89]	1726 [84]
			Post-1970 annual dataset				
1-year horizon	0.64	[0.58,0.69]	4465 [103]	**0.74**	§	[0.7,0.79]	4373 [103]
2-year horizon	**0.78**	[0.75,0.81]	4465 [102]	**0.85**	§	[0.83,0.87]	4373 [102]
3-year horizon	**0.8**	[0.77,0.82]	4465 [102]	**0.88**	§	[0.87,0.9]	4373 [102]
Emerging markets	**0.77**	[0.72,0.82]	823 [33]	**0.82**		[0.78,0.87]	804 [33]
Quality data	**0.8**	[0.76,0.84]	3325 [77]	**0.86**	§	[0.84,0.89]	3256 [77]
			Post-1970 quarterly dataset				
1-year horizon	**0.84**	[0.82,0.86]	19126 [104]	**0.93**	§	[0.92,0.94]	19061 [104]
2-year horizon	**0.85**	[0.84,0.86]	19126 [102]	**0.95**	§	[0.95,0.96]	19061 [102]
3-year horizon	**0.84**	[0.83,0.85]	19126 [101]	**0.96**	§	[0.95,0.96]	19061 [101]
Q4 only	**0.77**	[0.74,0.8]	4820 [103]	**0.83**	§	[0.8,0.85]	4800 [103]
Emerging markets	**0.88**	[0.86,0.89]	3110 [30]	**0.95**	§	[0.94,0.96]	3110 [30]
Quality data	**0.86**	[0.84,0.87]	15033 [84]	**0.96**	§	[0.95,0.96]	15010 [84]

Notes: Dependent variable:1/2/3-year horizon before crisis. § H_0: $AUC_{many} - AUC_{restricted} = 0$. **Bold** H_0: $AUC - AUC_{logitFE\&IA} = 0$. All tests at the 5% significance level. Long-run sample restricted selection: Loans/GDP (gap), Public Debt/GDP (gap), Narrow Money/GDP (gap), LT Interest Rate, GDP (gr), Inflation, Exchange Rate (gap), Loans/GDP, Public Debt/GDP, LT Interest Rate (n). Long-run sample many predictors: see table A1 in the data appendix. Annual post-1970 sample restricted selection: Loans/GDP (gap), Public Debt/GDP (gap), GDP (gap), Inflation, Real Exchange Rate (gap), Loans/GDP, Public Debt/GDP, Net Exports/GDP (gap). Annual post-1970 sample many predictors: see table A2 in the data appendix. Quarterly post-1970 sample restricted selection: Loans (gap), Loans (gr), Foreign Liabilities (gap)(glo), LT Interest Rate (gap)(glo), GDP (gap)(glo), Inflation, Exchange Rate (gap), Reserves (gap), GDP (gr)(glo). Quarterly post-1970 sample many predictors: see table A3 in the data appendix.

length of the horizon. This implies that it is harder to assess whether there will be a crisis next year than to assess whether there will be a crisis within the next few years. This conforms to accounts which picture banking crisis risks as building up slowly over time. At the same time, the actual crisis realization is less determinate – usually triggered by a shock, which may or may not occur in any particular year.

EWS's may provide different results for different banking crisis dummies. In order to investigate whether the high AUCs are specific to the banking crisis dummy by Schularick and Taylor (2012), table 5.4 displays AUCs obtained for the banking crisis dummy by Reinhart and Rogoff (2010) (RR dummy). The mean AUC estimates for the RR dummy are only marginally lower, otherwise the core results hold: the CTE model ouperforms the logit model based on the same set of predictors and the inclusion of many predictors significantly improves forecasts.

For the post-1970s datasets it is possible to look at emerging markets- (EM) subsamples.[22] Despite the fact that the EM subsamples contain only about a third of the crisis-events from the full sample, the EM AUC estimates are remarkably similar to the baseline results. Note, however, that in the annual post-1970 EM sample the inclusion of many predictors no longer significantly improves the AUC.

Excluding countries of presumably poor data quality[23] reduces the number of crises by about one fifth (from approximately 100 to around 80). AUCs tend to improve marginally by about 0.01. The fact that the exclusion of noisy data and several outliers does not significantly alter the results, highlights the robustness of the recursive partitioning algorithm.[24]

Finally, AUCs for the quarterly dataset are systematically higher than for the two annual samples, particularly in the case with many predictors. This is not due to the slightly different set of predictors contained in the quarterly sample. This can be seen in the "Q4 only" row of table 5.4 that reports the AUCs for a random forest model estimated only with the 4th quarter-observations from the quarterly dataset. In this case, AUC estimates converge with those for the two annual samples. CTEs seem to thrive on the larger number of observations contained in the quarterly sample.

In summary, the core results hold up very well: The CTE-based EWS's yield significantly higher AUCs than the logit alternative and the inclusion of many predictors further improves the accuracy of banking crisis predictions.

5.5. Case Study: 2007/2008

To round out this study, the performance of the $\mathcal{RF}$ EWS based on many predictors is compared with the IA-logit EWS in forecasting the 2007/2008 global financial crisis. Both

[22] The emerging markets subsample consists of Argentina, Brazil, Bulgaria, Chile, China, Colombia, Costa Rica, Croatia, Ecuador, Egypt, Hungary, India, Indonesia, Lithuania, Malaysia, Mexico, Morocco, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Romania, Thailand, Turkey and Vietnam

[23] Sample excludes Afghanistan, Angola, Benin, Burkina Faso, Burundi, Cambodia, Cape Verde, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Côte d'Ivoire, Djibouti, El Salvador, Eritrea, Ethiopia, Fiji, The Gambia, Grenada, Guinea-Bissau, Haiti, Lao People's Democratic Republic, Liberia, Libya, Mali, Mauritania, Mozambique, Myanmar, Niger, Nigeria, Rwanda, Sierra Leone, Swaziland, Syria, Timor-Leste, Togo, Uganda, Yemen and Zambia.

[24] Recall that recursive partitioning is robust to outliers since extreme values do not influence the internally optimal split points. Noise-resilience also appears to make CTEs outperform one of their most prominent competitors – boosting – whose out-of-sample AUC estimates appear to be held back by the level of noise in macroeconomic data (also see Long and Servedio, 2010) (see the appendix for results and further discussion of boosting-based EWS).

EWS's are estimated using the long-run sample, where only the data up to 1997 is incorporated and the rest of the data is used as test data. The resulting crisis probability estimates for the test data (1998 to 2011) are reported in figure 5.3.

It is immediately clear that the $\mathcal{RF}$ crisis risk evaluation exhibits considerably more variation than the logit model. For most countries it would have signaled a build-up in crisis risk in the mid-2000s. Thus, the $\mathcal{RF}$ model would have signaled rather clearly that the developed world as a whole was embarking upon a path, which historically has often ended in crisis. The evidence for the logit model is less flattering. While for some countries it signals a (slightly) higher crisis risk, for others it signals no big changes or even shows an increasing resilience during the 2000s.

The $\mathcal{RF}$ model produces mixed results with respect to the country-specific incidence of the 2007/2008 crisis. For the following countries crisis risk went up and a crisis did indeed occur: Belgium, Switzerland, Denmark, Spain, France, UK, Italy, Netherlands, Portugal, Sweden and the USA. Although the $\mathcal{RF}$ crisis risk is upward trending for all of these countries, its level is relatively low for some, namely Switzerland and the USA. Germany, for which crisis risk does not even trend upwards, also exhibits a very low risk level. How can these cases be explained? What brought down German and Swiss banks was their exposure to foreign assets. For the USA, nonbank intermediation was at the heart of its banking crisis. Neither exposure to foreign assets, nor nonbank intermediation are well reflected by any of the base indicators in the long-run sample. Extending the list of base indicators may help improve forecasts.

Several countries show clear signs of being in a danger zone prior to 2007/2008, but did not experience a systemic banking crisis according to the binary indicator: Australia, Canada, Finland, Norway. There is a notable concentration of Scandinavian countries and primary good exporters in this group. Hardy and Pazarbasioglu (1998) show that primary-product exporting countries possess a distinct set of early-warning indicators, which might explain the poor performance of the $\mathcal{RF}$-EWS in these cases. What is also interesting is that, excluding Canada, all of these countries experienced a banking crisis in the late 1980s or early 1990s. The ensuing institutional changes might have rendered their banking systems more resilient 20 years later. Giannone, Lenza and Reichlin (2010) present related evidence for the importance of regulatory quality in credit markets for explaining cross-country differences in weathering the global recession. Also note, that in Australia and Norway banking systems did in fact come under considerable stress during the relevant period – they are knife-edge cases with respect to the dummy categorization that was applied.

The last group consists of countries that did not see their risk profiles rise and indeed did not experience a systemic event: Japan is the only country in this category.

Formalizing these observations into conditional[25] out-of-sample AUC measures yields AUCs of 0.53 and 0.76 for the logit and $\mathcal{RF}$ model, respectively. The difference is statisti-

[25]"Conditional" as it is used here, refers to the fact that results are conditional on this particular 1998-2011 test dataset.

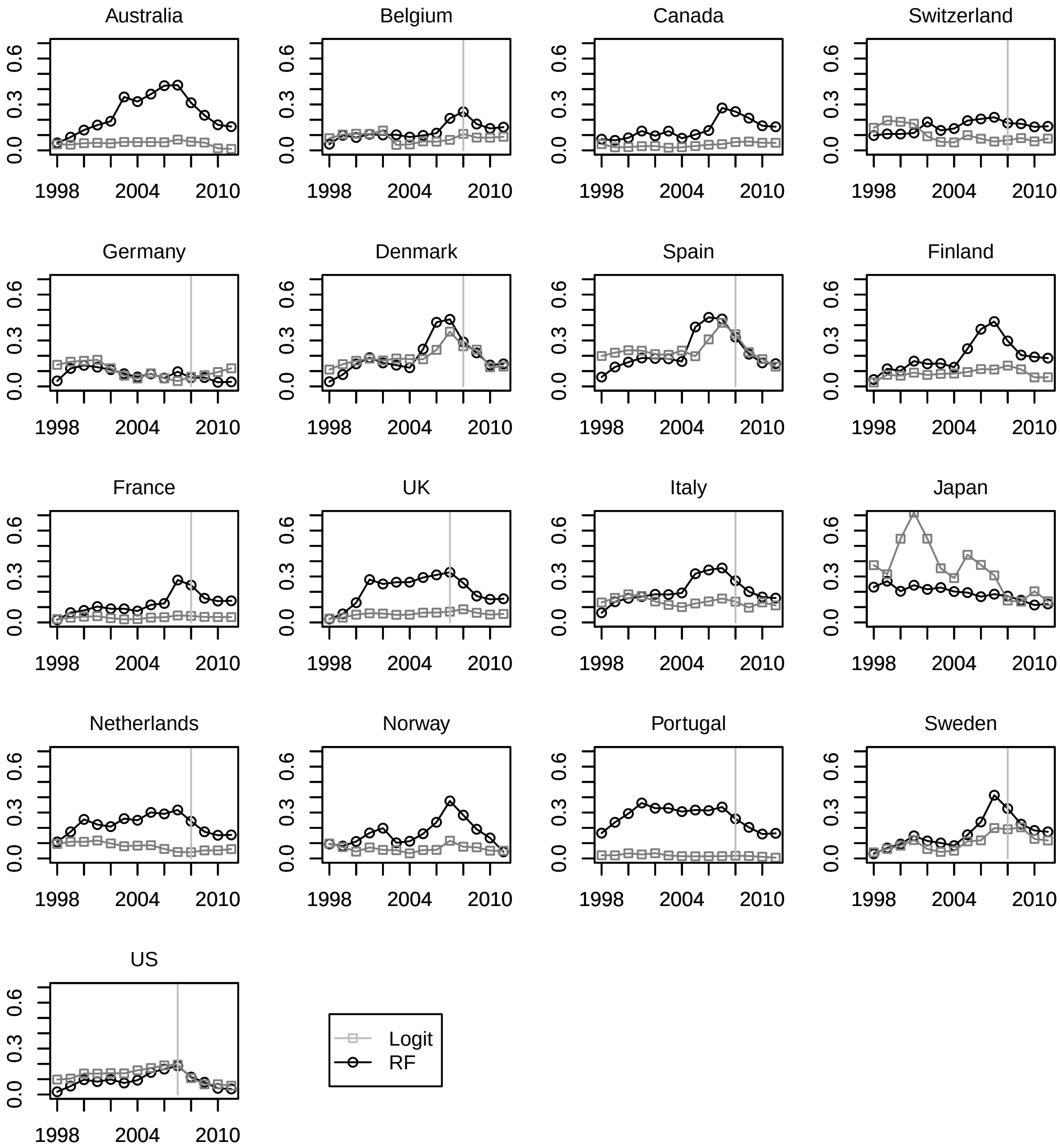


Figure 5.3: *The 2007/2008 Global Financial Crisis*

Notes: 1998-2011 out-of-sample probability estimates of being in the two year horizon before a banking crisis for 17 countries. 10 country-year observations between 1998 and 2011 exhibit missing values and were replaced by the respective variable's mean to obtain a probability estimate. Vertical gray bars indicate years with a systemic banking crisis.

cally significant (p-value=0.00)[26], while the logit AUC does not significantly differ from the uninformative 0.5 at the 5% significance level.

In summary, the results of the $\mathcal{RF}$ model on the most recent crisis is mixed. While the

[26]The p-value corresponds to the test for equality of AUCs by (DeLong, DeLong and Clarke-Pearson, 1988).

model would not have performed as convincingly with respect to the country-specific incidence of the crisis, it would have clearly signaled that the developed world as a whole, was on a dangerous path from the early 2000s on. The first part of this conclusion nicely mirrors results reported by Claessens et al. (2010), Rose and Spiegel (2010*b*), Rose and Spiegel (2010*a*) and Rose and Spiegel (2012), who find that prior to the global financial crisis hardly any predictor conveyed reliable information about the crisis' subsequent cross-country severity. While Rose and Spiegel (2012) continue to argue that their results warrant skepticism towards the potential of EWS to accurately predict a crisis, the analysis provided above suggests a different conclusion. Although even CTE EWS would have found predicting the 2007/2008 crises somewhat more difficult than their historical track record suggests, their use is still generally very promising. Also note that the evaluation of the $\mathcal{RF}$ EWS's performance in 2007/2008 depends on the categorization of two knife-edge cases. Given a more lenient evaluation of these cases (Australia and Norway) figure 5.3 shows that even in terms of cross-country incidence for 2007/2008 the $\mathcal{RF}$ predictor did not perform badly. Especially if combined with country-specific knowledge, as exemplified above, the proposed $\mathcal{RF}$-EWS would have given policy makers a valuable warning as to the vulnerability of the world financial system prior to the crisis.

5.6. Conclusion

This paper explored the potential of classification tree ensembles (CTEs) for forecasting binary banking crisis indicators. Their out-of-sample performance surpasses current best-practice early-warning systems that are based on logit models, by a substantial margin. The good forecasting performance of CTEs contrasts with the poor performance of single classification trees. However, the combination of many classification trees into an ensemble on the one hand, and the making use of many predictors on the other, result in an EWS that has the potential to provide policy-makers with a substantially more accurate assessment of banking crisis risk than current alternatives.

5.A. Appendix

5.A.1. Data Appendix

The following is a more precise account of the predictors used in the analysis:

1. In regard to the gap measure I used deviations from a slowly adjusting HP-trend (λ = 1600), which captures the slow build-up of financial imbalances (see Borio and Drehmann, 2009). Since the following is an exercise in forecasting, I used a one-sided HP-filter (Mehra, 2004).

2. I standardized the "to GDP" ratios when there was a lack of cross-country comparability between series, e.g. the loan aggregates (see Schularick and Taylor, 2012).

3. I calculated the global averages at time t as the GDP-weighted average of all countries with values at time t. For the quarterly post-1970 sample I calculated the non-weighted global average, due to the limited availability of quarterly PPP GDP data.

4. I calculated the real exchange rate for observation i as: $RER_i = NER_i \cdot P_i/P^*$, where NER_i denotes the nominal USD-exchange rate in price notation, P_i is the domestic CPI and P^* is the U.S. CPI.

5. I obtained the interest rate differential-predictors by subtracting global average interest rates from country interest rates.

6. Specifically for the logit analysis I generated six interaction terms.[27] I proxied private debt servicing costs by the multiplicative interaction-term of the Loans/GDP (gap) with long-term interest rates. Analogously public debt servicing costs are proxied by Public Debt/GDP (gap) x long-term interest rates (see Jordà, 2014). I defined the joint debt burden as the interaction-term of long-term rates with the Loans/GDP (gap) and the Public Debt/GDP (gap). The remaining three interaction terms are: Loans/GDP x GDP (gr) and Public Debt/GDP x GDP (gr) – aimed at capturing debt sustainability considerations in the face of low GDP realizations – and Loans/GDP (gap) x Exchange Rate (gap) – aimed at capturing effects from devaluations on the banking system.

I only make use of predictors which are broadly available across countries and time, because the limited number of crisis observations does not allow for large data losses due to missing values. For each of the three samples I eventually opt for an eclectic, though to some extent ad hoc, selection of $\approx$ 70 predictors. The number of predictors is often considered as a fine-tuning parameter. Such fine-tuning however is problematic when it comes to banking crisis forecasting for several reasons: Given the rarity of severe banking crises, setting aside part of the data for tuning considerations (i.e. validation data) is an excessive strain on the samples. Also, the crisis dummy bunches together a variety of different types of banking crises. This makes large training datasets necessary for any statistical procedure to uncover the different predictor signatures that foretell the advent of such a generically defined crisis event.

[27] I do not use these interaction terms in the classification tree-based analysis, as classification trees automatically identify important predictor interactions.

Finally, although the paper replicates results in more than one dataset, they are not entirely independent. These conditions leave little room for fine-tuning the model, as is commonly done in "big data" applications where separate validation data is more readily available. When it comes to forecasting banking crises, parsimony with respect to data is important.[28]

An exhaustive list of all predictors can be found in tables 5.5, 5.6 and 5.7.[29] These can be compared to other variable selections found in the literature (table 5.14).

[28]For the stated reasons, this paper makes use of default settings sourced from the literature also with respect to other fine-tuning parameters, such as tree growth stopping rules.

[29]Note the extreme means and standard deviations that show up for some predictors in tables A1 to A3. These are due to extreme outliers (e.g. those associated with the German hyperinflation of 1923). No attempt was made to remove these outliers, because the estimation of internally optimal split points via recursive partitioning renders classification trees immune to them.

Table 5.5: *Indicators*

Indicator	Obs.	Mean	S.D.	5th perc.	95th perc.
Bank Assets (gap)(glo)	2380	2.77	4.58	-4.06	9.30
Bank Assets (gr)(glo)	2397	0.05	0.04	-0.01	0.11
Bank Assets/GDP (gap)(glo)	2380	-0.02	1.02	-1.97	1.47
Bank Assets/GDP (glo)	2414	9.03	2.25	4.18	11.53
Bank Assets/GDP (gr)(glo)	2397	0.00	0.01	-0.01	0.02
Broad Money (gap)(glo)	2380	3.06	5.42	-3.71	9.07
Broad Money (gr)(glo)	2397	0.04	0.03	-0.02	0.08
Broad Money/GDP (gap)(glo)	2380	0.11	2.35	-3.12	2.69
Broad Money/GDP (glo)	2414	10.46	1.68	9.27	14.40
Broad Money/GDP (gr)(glo)	2397	0.00	0.02	-0.02	0.03
C (gap)	2261	1.28	7.53	-8.82	13.18
C (gap)(glo)	2380	1.19	4.17	-6.09	9.24
C (gr)	2278	0.02	0.06	-0.06	0.09
C (gr)(glo)	2397	0.02	0.02	-0.03	0.05
C/GDP	2140	8.64	19.78	0.00	43.67
C/GDP (gap)	2079	0.96	6.40	-8.11	10.64
C/GDP (gap)(glo)	2380	0.65	5.31	-6.19	6.05
C/GDP (glo)	2414	10.04	4.93	5.08	18.98
C/GDP (gr)	2109	-0.01	0.06	-0.08	0.06
C/GDP (gr)(glo)	2397	-0.01	0.04	-0.05	0.03
Exchange Rate (gap)	2380	3.21	25.98	-18.10	35.34
Exchange Rate (gr)	2397	249,929.16	12236321.00	-0.14	0.22
Exchange Rate (n)	2414	45.79	196.22	0.05	166.00
GDP (gap)	2192	1.22	7.17	-8.29	11.84
GDP (gap)(glo)	2380	1.49	4.97	-5.30	9.68
GDP (gr)	2223	0.02	0.06	-0.06	0.10
GDP (gr)(glo)	2397	0.02	0.03	-0.04	0.07
I (gap)(glo)	2380	4.56	23.95	-21.74	36.39
I (gr)(glo)	2397	0.08	0.34	-0.13	0.31
I/GDP (gap)(glo)	2380	1.67	17.70	-21.94	22.97
I/GDP (glo)	2414	0.18	0.04	0.12	0.24
I/GDP (gr)(glo)	2397	0.03	0.23	-0.12	0.22
Inflation	2363	0.04	0.15	-0.06	0.17
Inflation (glo)	2397	0.04	0.07	-0.04	0.18
LT Interest Rate	2259	0.02	0.12	-0.11	0.10
LT Interest Rate (gap)	2197	-0.00	0.09	-0.08	0.07
LT Interest Rate (gap)(glo)	2363	-0.00	0.04	-0.08	0.06
LT Interest Rate (glo)	2397	0.02	0.06	-0.11	0.09
LT Interest Rate (n)	2300	0.06	0.03	0.03	0.12
LT Interest Rate (n)(gap)	2242	-0.00	0.01	-0.02	0.01
LT Interest Rate (n)(gap)(glo)	2380	-0.00	0.01	-0.01	0.01
LT Interest Rate (n)(glo)	2414	0.05	0.02	0.03	0.10
LT Interest Rate Diff.	2259	-0.00	0.10	-0.07	0.09
LT Interest Rate Diff. (n)	2300	0.00	0.02	-0.02	0.03
Loans (gap)	2151	4.50	15.41	-17.75	27.13
Loans (gap)(glo)	2380	3.34	9.29	-13.00	20.28
Loans (gr)	2177	0.05	0.12	-0.09	0.20
Loans (gr)(glo)	2397	0.05	0.06	-0.03	0.15
Loans/GDP	2101	10.00	1.00	8.61	11.77
Loans/GDP (gap)	2035	0.05	2.63	-4.40	4.28

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Table A1: Indicators (continued)

Indicator	Obs.	Mean	S.D.	5th perc.	95th perc.
Loans/GDP (gap)(glo)	2380	-0.07	2.83	-5.73	4.81
Loans/GDP (glo)	2414	9.68	2.14	2.93	11.73
Loans/GDP (gr)	2068	0.00	0.02	-0.02	0.03
Loans/GDP (gr)(glo)	2397	0.00	0.01	-0.02	0.02
Narrow Money (gap)	2150	3.59	11.86	-12.69	24.15
Narrow Money (gap)(glo)	2380	3.56	7.71	-8.24	18.75
Narrow Money (gr)	2183	0.04	0.10	-0.08	0.18
Narrow Money (gr)(glo)	2397	0.04	0.05	-0.03	0.12
Narrow Money/GDP (gap)	2075	0.68	3.08	-3.77	5.65
Public Debt (gap)	2135	5.75	22.14	-19.11	39.48
Public Debt (gap)(glo)	2380	8.97	16.09	-8.69	36.90
Public Debt (gr)	2169	0.04	0.17	-0.11	0.24
Public Debt (gr)(glo)	2397	0.05	0.12	-0.04	0.24
Public Debt/GDP	2207	0.54	0.39	0.10	1.20
Public Debt/GDP (gap)	2135	13.98	109.21	-21.77	47.65
Public Debt/GDP (gap)(glo)	2380	8.97	16.09	-8.69	36.90
Public Debt/GDP (glo)	2414	0.66	0.29	0.34	1.09
Real Exchange Rate	2384	10.00	0.97	8.96	11.95
Real Exchange Rate (gap)	2342	-0.10	2.74	-4.21	3.52
Real Exchange Rate (gr)	2363	0.00	0.02	-0.03	0.03
ST Interest Rate (gap)(glo)	2363	-0.00	0.04	-0.06	0.07
ST Interest Rate (glo)	2397	0.01	0.07	-0.10	0.08
ST Interest Rate (n)(gap)(glo)	2380	0.00	0.01	-0.02	0.02
ST Interest Rate (n)(glo)	2414	0.05	0.02	0.02	0.09
Stock Prices (gap)(glo)	2380	22.10	62.05	-28.26	108.38
Stock Prices (gr)(glo)	2397	0.03	0.15	-0.23	0.25

Notes: (n) nominal; (gr) growth; (glo) global GDP-weighted average; (gap) percentage deviation from (one-sided) HP-trend (λ = 1600). The high mean and standard deviation for the exchange rate growth predictor are due to the German hyperinflation of 1923.

Table 5.6: *Indicators, annual post-1970 sample*

Indicator	Obs.	Mean	S.D.	5th perc.	95th perc.
C (gap)	5821	3.15	10.69	-10.24	18.94
C (gap)(glo)	6440	3.50	2.95	-1.04	8.47
C (gr)	5979	0.04	0.10	-0.10	0.17
C (gr)(glo)	6601	0.05	0.03	-0.00	0.10
C/GDP	6157	0.66	0.17	0.39	0.92
C/GDP (gap)	5841	2.87	205.36	-11.32	10.29
C/GDP (gap)(glo)	6440	2.08	3.57	-2.93	7.72
C/GDP (glo)	6762	0.58	0.03	0.53	0.62
C/GDP (gr)	5999	0.00	0.09	-0.10	0.11
C/GDP (gr)(glo)	6601	-0.00	0.04	-0.06	0.06
Exchange Rate (n)	6197	301.52	1341.10	0.00	1083.01
Exchange Rate (n)(gap)	5881	14.69	42.79	-18.94	85.78
Exchange Rate (n)(gr)	6039	3.6e+05	2.8e+07	-0.11	0.79
GDP (gap)	5821	3.35	12.31	-9.82	20.46
GDP (gap)(glo)	6440	2.18	4.31	-5.38	8.57
GDP (gr)	5979	0.02	0.06	-0.07	0.10
GDP (gr)(glo)	6601	0.03	0.03	-0.02	0.07
I (gap)	5821	12.62	278.75	-29.92	49.16
I (gap)(glo)	6440	4.93	9.61	-13.16	18.03
I (gr)	5979	0.06	0.44	-0.25	0.39
I (gr)(glo)	6601	0.08	0.13	-0.07	0.23
I/GDP	6157	0.23	0.09	0.09	0.39
I/GDP (gap)	5841	1.99	21.27	-27.49	35.00
I/GDP (gap)(glo)	6440	0.56	7.31	-13.42	10.09
I/GDP (glo)	6762	0.27	0.03	0.23	0.32
I/GDP (gr)	5999	0.02	0.51	-0.25	0.32
I/GDP (gr)(glo)	6601	0.02	0.11	-0.13	0.16
Inflation	5979	3.7e+05	2.9e+07	-0.01	0.71
Inflation (glo)	6601	12671.34	80145.44	0.09	0.48
LT Interest Rate (gap)(glo)	6440	-0.13	0.83	-1.66	1.46
LT Interest Rate (gap)(glo)	6279	-0.12	0.84	-1.74	1.79
LT Interest Rate (glo)	6601	5.85	3.04	1.91	10.45
LT Interest Rate (n)(glo)	6762	5.79	3.02	1.88	10.52
Loans (gap)	4936	14.44	149.33	-28.34	62.48
Loans (gap)(glo)	6440	4.71	9.75	-14.90	21.53
Loans (gr)	5099	3.8e+06	2.7e+08	-0.20	0.43
Loans (gr)(glo)	6601	326.77	2065.77	-0.04	0.34
Loans/GDP	5294	10.00	0.99	8.74	11.87
Loans/GDP (gap)	6440	-0.36	2.46	-6.16	2.74
Loans/GDP (gap)	4960	0.66	4.71	-7.26	8.64
Loans/GDP (glo)	6762	10.21	2.06	7.47	13.17
Loans/GDP (gr)	5127	0.01	0.04	-0.04	0.06
Loans/GDP (gr)(glo)	6601	0.01	0.02	-0.01	0.03
Net Exports (gap)	5813	-4.94	1510.24	-189.64	220.52
Net Exports (gap)(glo)	6440	10.31	91.74	-177.73	191.82
Net Exports (gr)	5964	-0.33	17.49	-2.38	2.27
Net Exports (gr)(glo)	6601	-0.55	3.63	-3.87	2.10
Net Exports/GDP	6157	-0.06	0.17	-0.31	0.15
Net Exports/GDP (gap)	5833	-7.08	3359.35	-193.22	209.44
Net Exports/GDP (gap)(glo)	6440	-98.12	941.21	-127.61	138.78

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Table A2: Indicators, annual post-1970 sample (continued)

Indicator	Obs.	Mean	S.D.	5th perc.	95th perc.
Net Exports/GDP (glo)	6762	-0.00	0.03	-0.04	0.04
Net Exports/GDP (gr)	5984	-0.34	16.79	-2.37	2.13
Net Exports/GDP (gr)(glo)	6601	-0.55	3.45	-3.74	1.79
Public Debt (gap)	4780	4.90	88.01	-29.00	38.47
Public Debt (gr)	5009	0.07	0.27	-0.19	0.43
Public Debt (gr)(glo)	6601	0.08	0.22	-0.06	0.29
Public Debt/GDP	5388	62.18	65.19	10.41	158.71
Public Debt/GDP (gap)	4913	7.20	158.25	-37.52	45.04
Public Debt/GDP (gap)(glo)	6762	40.54	15.50	15.56	65.75
Public Debt/GDP (gap)(glo)	6440	3.00	16.65	-20.92	35.54
Public Debt/GDP (gap)(glo)	6440	3.00	16.65	-20.92	35.54
Real Exchange Rate	6137	10.00	0.98	8.82	11.80
Real Exchange Rate (gap)	5821	0.51	3.60	-5.86	6.65
Real Exchange Rate (gr)	5979	0.01	0.03	-0.03	0.05
ST Interest Rate (gap)(glo)	6279	-26.53	303.98	-567.80	212.32
ST Interest Rate (glo)	6601	77.58	351.66	4.83	49.50
ST Interest Rate (n)(gap)(glo)	6440	-25.78	300.19	-502.86	118.05
ST Interest Rate (n)(glo)	6762	76.06	347.62	4.90	50.04
Stock Prices (gap)(glo)	6440	61.01	71.81	1.24	229.83
Stock Prices (gr)(glo)	6601	0.05	0.38	-0.33	0.79

Notes: (n) nominal; (gr) growth; (glo) global GDP-weighted average; (gap) percentage deviation from (one-sided) HP-trend (λ = 1600). With the exception of the level predictors, the high means and standard deviations for the exchange rate-, inflation- and loan predictors are due to outlier values found for the following countries: Bolivia, the Democratic Republic of Congo, Georgia, Nicaragua, Nigeria, Serbia and Zimbabwe.

Table 5.7: *Indicators, quarterly post-1970 sample*

Indicator	Obs.	Mean	S.D.	5th perc.	95th perc.
CPI	22279	65.27	59.65	0.27	139.27
CPI (glo)	30780	0.04	0.04	0.01	0.09
Exchange Rate (n)(gap)	27866	4.16	51.78	-10.72	23.99
Exchange Rate (n)(gr)	28051	14.76	2201.33	-0.06	0.13
Foreign Liabilities (gap)(glo)	30600	23.76	43.45	-0.98	102.19
Foreign Liabilities (glo)	30960	215.68	159.83	26.62	605.61
Foreign Liabilities (gr)(glo)	30780	1.3e+06	1.7e+07	-0.01	0.52
Foreign Liabilities (n)(gap)(glo)	30600	18.75	70.67	0.27	37.65
Foreign Liabilities (n)(glo)	30960	6.6e+10	8.6e+11	113.11	84491.38
Foreign Liabilities (n)(gr)(glo)	30780	7.1e+06	7.8e+07	0.02	1.74
Foreign Liabilities/GDP (gap)(glo)	30600	0.15	1.92	-2.31	2.39
Foreign Liabilities/GDP (glo)	30960	10.00	0.32	9.73	10.44
Foreign Liabilities/GDP (gr)(glo)	30780	-0.06	0.72	-0.02	0.10
GDP (gap)(glo)	30600	114.90	497.82	-209.48	507.08
GDP (glo)	30960	7404.10	41252.75	-996.98	34855.12
GDP (gr)(glo)	30780	0.26	6.27	-2.00	3.14
GDP (n)(gap)(glo)	30600	57.42	234.64	-251.87	356.51
GDP (n)(glo)	30960	3.55	1.97	0.45	6.08
GDP (n)(gr)(glo)	30780	0.33	6.18	-3.32	4.66
House Prices (gap)(glo)	30060	-0.00	2.88	-5.22	3.56
House Prices (glo)	30420	3.75	3.32	1.36	11.31
House Prices (gr)(glo)	30240	0.00	0.01	-0.02	0.03
House Prices (n)(gap)(glo)	30600	0.55	3.02	-5.16	5.22
House Prices (n)(glo)	30960	373.19	495.26	42.69	1542.70
House Prices (n)(gr)(glo)	30780	0.02	0.02	-0.00	0.05
Inflation	21866	0.04	0.35	-0.01	0.11
Inflation (glo)	30780	0.04	0.04	0.01	0.09
LT Interest Rate (glo)	30780	9.76	2.92	6.06	12.87
LT Interest Rate (n)(glo)	30960	10.69	3.38	6.28	15.27
LT Interest Rate Diff. (glo)	30780	-0.00	0.00	-0.00	0.00
LT Interest Rate Diff. (n)(glo)	30960	-0.00	0.00	-0.00	0.00
Loans	20266	1015.99	2947.06	1.28	5872.05
Loans (gap)	19775	20.82	1828.59	-13.20	24.86
Loans (gap)(glo)	30600	16.96	136.05	-1.06	31.13
Loans (glo)	30960	973.98	571.51	493.79	2331.87
Loans (gr)	19961	0.02	0.11	-0.09	0.13
Loans (gr)(glo)	30780	0.02	0.02	-0.00	0.06
Loans (n)	24234	2.0e+14	3.1e+16	2.40	3.8e+05
Loans (n)(gap)	23729	7.86	165.20	-8.55	27.96
Loans (n)(gap)(glo)	30600	7.53	13.14	0.55	12.53
Loans (n)(glo)	30960	1.7e+14	2.2e+15	756.76	4.0e+05
Loans (n)(gr)	23920	2.6e+07	4.1e+09	-0.05	0.20
Loans (n)(gr)(glo)	30780	2.2e+07	2.9e+08	0.02	0.11
Loans/GDP (gap)(glo)	30600	0.08	1.03	-1.49	1.82
Loans/GDP (glo)	30960	9.97	0.20	9.79	10.30
Loans/GDP (gr)(glo)	30780	0.00	0.25	-0.03	0.08
Real Exchange Rate (gap)	21332	0.13	2.18	-3.26	3.43
Real Exchange Rate (gr)	21529	0.00	0.02	-0.02	0.02
Reserves	20982	7.1e+11	2.1e+13	0.46	2199.54
Reserves (gap)	20514	307.29	27492.34	-33.83	129.20

Continued on next page

Table A2: Indicators, quarterly post-1970 sample (continued)

Indicator	Obs.	Mean	S.D.	5th perc.	95th perc.
Reserves (gap)(glo)	30600	310.91	2723.12	-2.19	179.45
Reserves (glo)	30960	1.0e+12	2.6e+12	140.56	8.0e+12
Reserves (gr)	20719	0.03	0.66	-0.28	0.35
Reserves (gr)(glo)	30780	0.03	0.08	-0.05	0.14
Reserves (n)	25411	14489.74	96910.52	14.23	47255.90
Reserves (n)(gap)	24975	13.42	379.33	-31.25	54.95
Reserves (n)(gap)(glo)	30600	13.03	28.28	-3.51	39.61
Reserves (n)(glo)	30960	12554.25	15958.76	1239.33	53696.80
Reserves (n)(gr)	25178	0.07	0.86	-0.25	0.42
Reserves (n)(gr)(glo)	30780	0.07	0.09	-0.02	0.25
Reserves/GDP (gap)(glo)	30600	0.07	1.17	-1.71	2.32
Reserves/GDP (glo)	30960	9.96	0.18	9.74	10.34
Reserves/GDP (gr)(glo)	30780	0.00	0.10	-0.03	0.07
ST Interest Rate (glo)	30780	5011.86	57413.27	4.11	70.80
ST Interest Rate (n)(glo)	30960	4330.27	49689.00	4.24	72.36
ST Interest Rate Diff. (glo)	30780	0.00	0.00	-0.00	0.00
ST Interest Rate Diff. (n)(glo)	30960	-0.00	0.00	-0.00	0.00
Stock Prices (gap)(glo)	30600	7.48	14.26	-12.56	32.09
Stock Prices (glo)	30960	0.60	0.28	0.29	1.27
Stock Prices (gr)(glo)	30780	0.01	0.07	-0.11	0.10
Stock Prices (n)(gap)(glo)	30600	9.95	60.50	-7.98	20.45
Stock Prices (n)(glo)	30960	610.50	6942.76	6.78	135.30
Stock Prices (n)(gr)(glo)	30780	0.04	0.07	-0.08	0.15

Notes: (n) nominal; (gr) growth; (glo) global GDP-weighted average; (gap) percentage deviation from (one-sided) HP-trend (λ = 1600). With the exception of the level predictors, the high means and standard deviations for the foreign liability-, loan-, reserve- and ST rate predictors are due to outlier values found for the following countries: Argentina, Brazil, Cameroon, Eritrea, Guyana, Sierra Leone, Suriname and Zimbabwe.

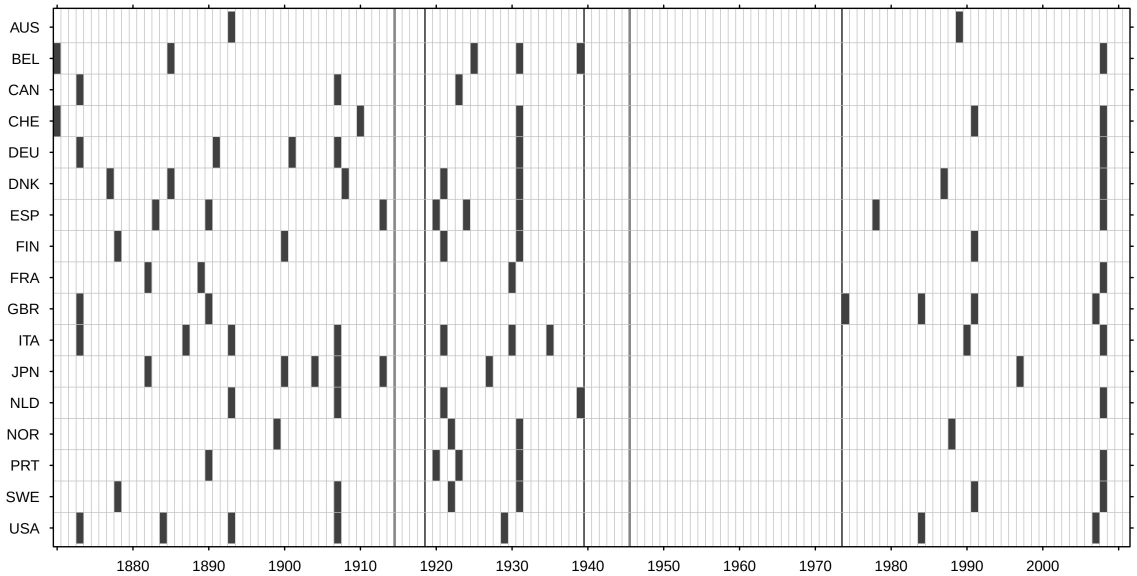

Figure 5.4: *Crisis Map: Long-run 1870-2011 sample*

Notes: Systemic banking crises (black). Source: Systemic banking crisis dummies from Schularick and Taylor (2012).

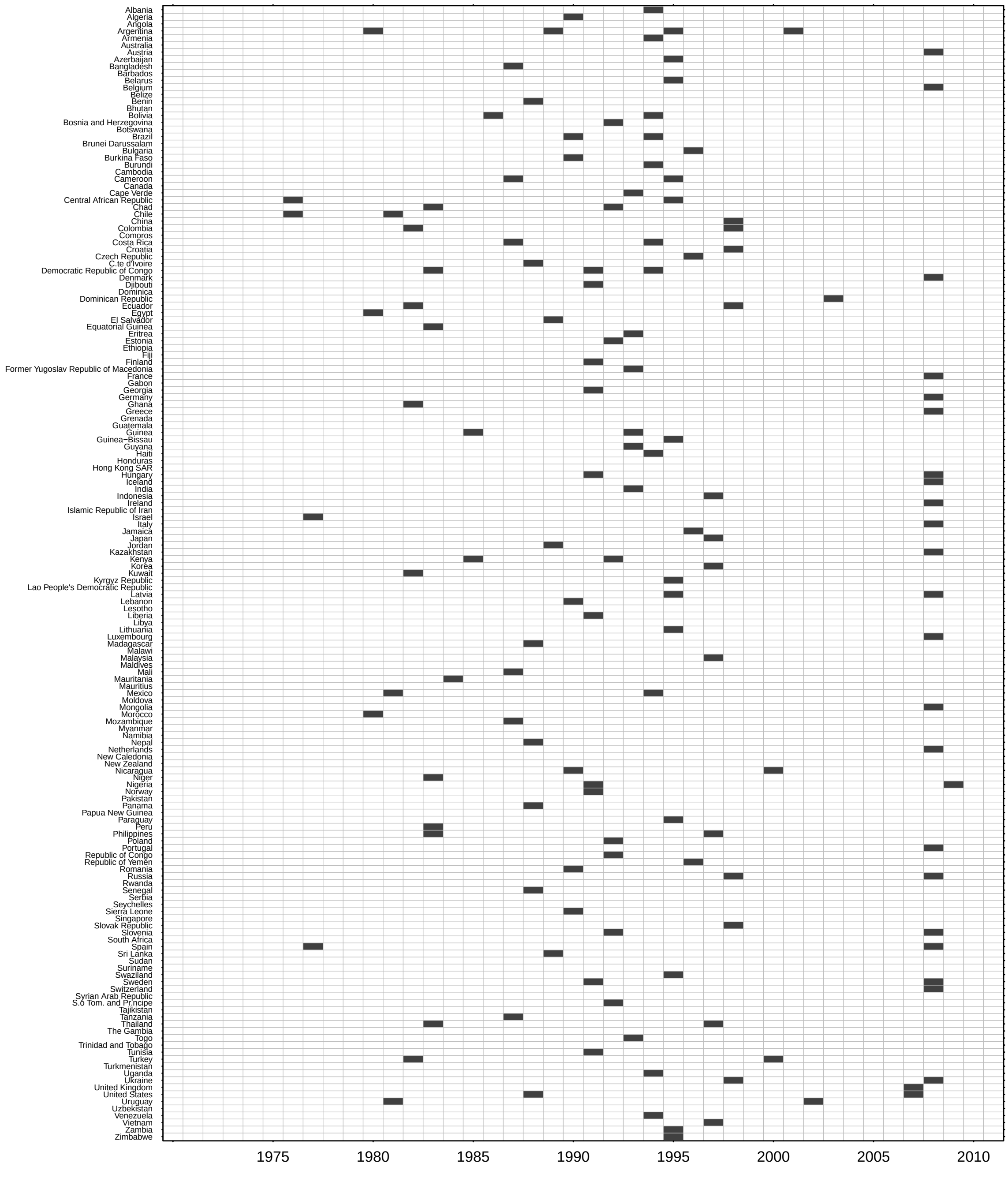

Figure 5.5: *Crisis Map: Post-1970 Samples*

Notes: Systemic banking crises (black). Source: Systemic banking crisis dummies from Laeven and Valencia (2013).

5.A.2. *Variable Importance*

This section discusses variable importance measures (VIMs) for classification tree ensembles by means of the random forest EWS estimated on the basis of the long-run (1870-2011) sample (corresponding to the results reported in table 3 that is included in the paper). The two most commonly applied VIMs are permutation importance[30] and gini importance. Permutation importance evaluates the importance of a predictor j according to the decrease in out-of-sample prediction accuracy, which results from the random permutation of that predictor. For each tree b the following variable importance measure is calculated:

$$VIM^b_{Perm}(j) = \frac{\sum_{i \in X_b} I(y_i = \hat{y}^b_i)}{|X_b|} - \frac{\sum_{i \in X_b} I(y_i = \hat{y}^b_{i,perm})}{|X_b|} \tag{5.1}$$

where X_b indicates the bootstrap sample on which the tree b is estimated and y_i is the binary crisis indicator. $|B_b|$ indicates the number of observations contained in bootstrap sample b. $\hat{y}^b_i$ is the model's out-of-bag (OOB) crisis prediction. It is either 0 or 1, depending on how observation i is categorized by the majority of trees for which it constitutes an out-of-bag (OOB) observation. $\hat{y}^b_{i,perm}$ is the same prediction made with the randomly permuted predictor j. If the permutation of j results in many more false warnings then j has a high variable importance $VIM^b_{Perm}(j)$. The final permutation importance measure is then obtained by averaging $VIM^b_{Perm}(j)$ over all B trees:

$$VIM_{Perm}(j) = \frac{\sum_{b=1}^{B} VIM^b_{Perm}(j)}{B} \tag{5.2}$$

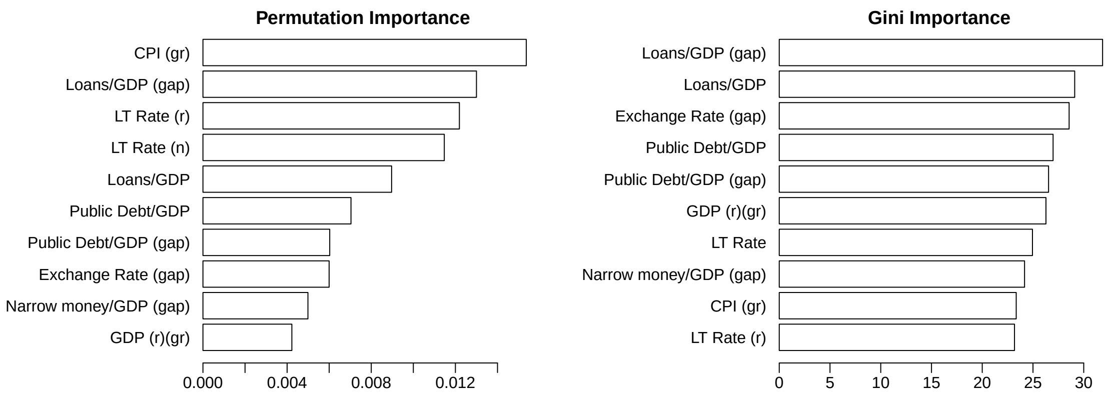

Figure 5.6: *Variable importances for the random forest model based on the restricted variable selection*

Notes: (n) nominal; (r) real; (gr) growth; (glo) global GDP-weighted average; (gap) percentage deviation from (one-sided) HP-trend (λ = 1600).

The left panel of figure 5.6 shows that according to this measure CPI inflation is the most important predictor in the restricted predictor set, followed by the Loans/GDP (gap) and

[30]The following discussion concentrates on the unscaled version of the permutation importance measure because its statistical properties compare favorably to the scaled version (see Díaz-Uriarte and De Andres, 2006; Strobl and Zeileis, 2008; Nicodemus et al., 2010).

long-term interest rates.

An alternative variable importance measure is the gini importance, which is the average of the sum of information gains $\mathcal{IG}$ in a tree across all B trees that are due to predictor j:

$$VIM_{Gini}(j) = \frac{1}{B}\sum_{b=1}^{B}\sum_{s=1}^{S_b}\mathcal{IG}(\widehat{t_j^s}) \tag{5.3}$$

where $\sum_{s=1}^{S_b}\mathcal{IG}(\widehat{t_j^s})$ is the sum of information gains across all splits s that occur along predictor j in tree b. The right panel of figure 5.6 shows the Gini importance ranking for the random forest model based on few predictors. The two Loans/GDP predictors come out on top of the ranking, followed by the exchange rate gap. The dissimilarity of the Gini- and Permutation importance rankings is striking. The only exception to this is the Loans/GDP (gap), which ranks high across both measures.

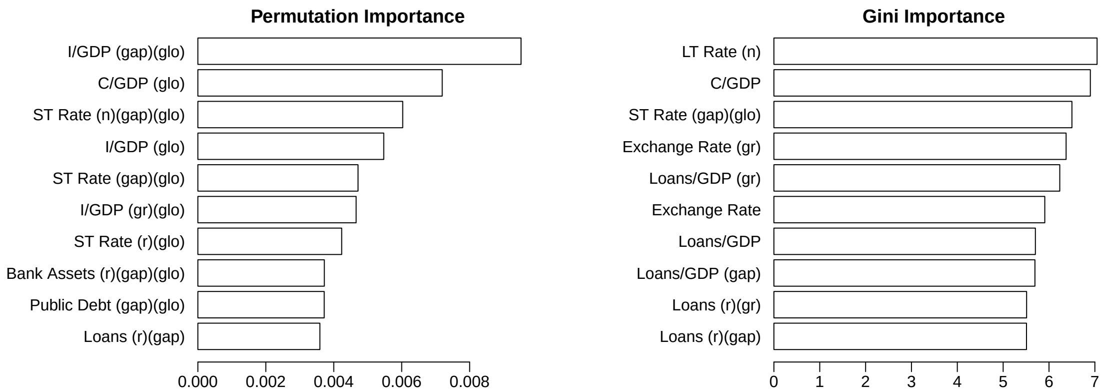

Figure 5.7: *Variable importances for the random forest model based on many predictors; top 10*

Notes: (n) nominal; (r) real; (gr) growth; (glo) global GDP-weighted average; (gap) percentage deviation from (one-sided) HP-trend (λ = 1600).

Figure 5.7 displays the top-10 predictors according to the Permutation- and Gini-importance measures for the random forest model based on many predictors. Yet again in this case, the two importance measures produce conflicting rankings with only two predictors showing up in both top-10: the ST Rate (gap)(glo) and the Loans (r)(gap). Otherwise the permutation-based measure is dominated by global predictors (glo), while the gini-based top-10 are dominated by domestic loans.

These results caution against the reliance on variable importance measures for identifying the main drivers behind banking crisis risk. Different importance measures can produce very different results.[31] Given that the theoretical analysis of the properties of different variable importance measures is in its early stages (see Ishwaran, 2007; Grömping, 2012; Louppe et al., 2013) and strong theoretical reasons for the adoption of one importance measure over another is lacking, it may be preferable to supplement CTE-based forecasts with additional modes of

[31]See the series of papers published in BMC Bioinformatics: Nicodemus, Wang and Shugart (2007), Strobl et al. (2007), Strobl et al. (2008), Nicodemus and Malley (2009) and Nicodemus et al. (2010).

assessing the relevance of particular risk factors.

5.A.3. *Robustness*

Post-1970 annual sample

Here, the analysis is repeated for the annual post-1970 sample in order to check whether the main results replicate. With the exception of a slightly different set of predictors, the analysis proceeds along the same lines as for the annual long-run sample. The main results hold up very well: Bagging and the inclusion of many predictors substantially improves the accuracy of banking crisis predictions.

The results are reported in table 5.8. As in the case of the long-run sample, a single classification tree estimated on the basis of the restricted set of seven predictors performs poorly (AUC = 0.54). This poor performance is again remedied through bagging: Compared to the single classification tree, the mean AUC estimate for the $\mathcal{F}$ estimator jumps by more than 0.2 to 0.76. The additional randomization in the $\mathcal{RF}$ estimator (AUC=0.78) is again associated with a 0.02 increase in the mean AUC estimate. Estimation on the basis of 70 predictors yields a second increase in predictive performance for the two CTEs. For both, a mean AUC estimate of 0.85 is calculated. Overall, the results for the annual long-run- and annual post-1970 sample are very similar.

Results for the quarterly post-1970 sample, with again a different set of predictors, confirms that two significant increases in out-of-sample predictive performance can be obtained by moving from single trees to tree ensembles, and from a few to many predictors.

Quarterly data

Table 5.9 illustrates the results for the quarterly post-1970 sample. For the quarterly data the mean AUC estimates are generally higher than for the long-run dataset and the annual post-1970 sample – regardless of specification. However, the mean AUC estimate for the single classification tree based on the restricted set of predictors (AUC=0.58) is still rather close to the uninformative 0.5. Once again it is their aggregation into an ensemble which renders classification trees fit for forecasting: the mean AUC estimate for the two CTEs that are based on the restricted set of predictors is 0.83. As opposed to the other two samples, the $\mathcal{RF}$ estimator does not perform better than the $\mathcal{F}$ estimator.

Estimation on the basis of the eclectic set of 73 predictors again improves forecasts. Even the single classification tree now achieves an AUC of 0.69. For the two CTEs I obtained high AUC estimates of 0.97 and 0.95. In this case, the additional randomization puts the $\mathcal{RF}$ estimator at a small disadvantage in comparison to the plain $\mathcal{F}$ estimator.

Table 5.10 shows how much of the improvement was due to the higher data frequency as opposed to the different predictor set. The results are for the same quarterly post-1970 data, but using only Q4 of each year. Stars (*) indicate that at the 5% significance level, the AUCs of the Q4-only analysis are significantly lower than the AUCs of the analysis that uses all

Table 5.8: *$\mathcal{CT}$-EWS: Annual Post-1970 Sample*

	Results					
	Restricted Selection			**Many Predictors**		
Model	AUC	95%-CI	N	AUC	95%-CI	N
Single Tree	0.54	[0.5,0.57]	4465	0.56 §	[0.52,0.6]	4373
Bagging	**0.76**	[0.73,0.8]	4465	**0.85** §	[0.83,0.87]	4373
Random Forest	**0.78**	[0.75,0.81]	4465	**0.85** §	[0.83,0.87]	4373
	Specification					
	Restricted Selection			**Many Predictors**		
Parameter	Single	Bagging	RF	Single	Bagging	RF
B	1	5000	5000	1	5000	5000
J_{try}	7	7	3	70	70	8
J		7			70	
# of crises		102			102	

Notes: Dependent variable: two-year horizon before crisis. Restricted Selection: Loans/GDP (gap), Public Debt/GDP (gap), GDP (gap), Inflation, Real Exchange Rate (gap), Loans/GDP, Public Debt/GDP, Net Exports/GDP (gap). Many Predictors: see table A2. For single tree: out-of-sample mean AUC- and confidence band estimates are based on Monte Carlo Cross-Validation (see Picard and Cook, 1984; Arlot, Celisse et al., 2010); 100 MC-draws of training (63,2%) - test (36,8%) data partitions. For ensembles: out-of-sample AUC-estimates (and confidence intervals) are based on out-of-bag (OOB)-data (see Breiman, 1996*b*). N number observations. J number of predictors under analysis. J_{try} number of predictors randomly selected and considered as a splitting variable at each recursive partitioning step. B number of trees. Specification table: If only the bagging column has an entry this means all models share the same specification. § H_0: $AUC_{many} - AUC_{restricted} = 0$. **Bold** H_0: $AUC - AUC_{logitFE\&IA} (= 0.62) = 0$. All tests at the 5% significance level. Logit specification: restricted variable selection + interaction terms as in table 5.2 + country fixed effects.

four quarters. This suggests that EWS's based on quarterly data will be more accurate than comparable EWS's based on annual data.

More generally, the strong performance across at least three datasets (differing in frequency, predictors as well as country- and time-coverage) suggests that CTEs are a reliable choice when it comes to forecasting a banking crisis.

Table 5.9: *$\mathcal{CT}$-EWS: Quarterly Post-1970 Sample*

	Results					
	Restricted Selection			**Many Predictors**		
Model	AUC	95%-CI	N	AUC	95%-CI	N
Single Tree	0.58	[0.55,0.6]	19126	**0.69** §	[0.66,0.72]	19061
Bagging	**0.85**	[0.83,0.86]	19126	**0.97** §	[0.97,0.98]	19061
Random Forest	**0.85**	[0.84,0.86]	19126	**0.95** §	[0.95,0.96]	19061
	Specification					
	Restricted Selection			**Many Predictors**		
Parameter	Single	Bagging	RF	Single	Bagging	RF
B	1	5000	5000	1	5000	5000
J_{try}	9	9	3	73	73	9
J		9			73	
# of crises		102			102	

Notes: Dependent variable: two-year horizon before crisis. Restricted Selection: Loans (gap), Loans (gr), Foreign Liabilities (gap)(glo), LT Interest Rate (gap)(glo), GDP (gap)(glo), Inflation, Exchange Rate (gap), Reserves (gap), GDP (gr)(glo). Many Predictors: see table 5.7. For single tree: out-of-sample mean AUC- and confidence band estimates are based on Monte Carlo Cross-Validation (see Picard and Cook, 1984; Arlot, Celisse et al., 2010); 100 MC-draws of training (63,2%) - test (36,8%) data partitions. For ensembles: out-of-sample AUC-estimates (and confidence intervals) are based on out-of-bag (OOB)-data (see Breiman, 1996*b*). N number observations. J number of predictors under analysis. J_{try} number of predictors randomly selected and considered as a splitting variable at each recursive partitioning step. B number of trees. Specification table: If only the bagging column has an entry this means all models share the same specification. § H_0: $AUC_{many} - AUC_{restricted}$ = 0. **Bold** H_0: $AUC - AUC_{logitFE\&IA}$(= 0.65) = 0. Logit specification: restricted variable selection + interaction terms in table 2 (main text) (excluding terms with public debt) + country fixed effects.

Table 5.10: *$\mathcal{CT}$-EWS: 4th Quarter only Post-1970 Sample*

	Results						
	Restricted Selection				**Many Predictors**		
Model	AUC	95%-CI	N		AUC	95%-CI	N
Single Tree	0.54	[0.51,0.58]	4820		**0.57**	[0.53,0.61]	4800
Bagging	**0.76**	[0.73,0.79]	4820		**0.84** §	[0.81,0.86]	4800
Random Forest	**0.77**	[0.74,0.8]	4820		**0.83** §	[0.8,0.85]	4800
	Specification						
	Restricted Selection				**Many Predictors**		
Parameter	Single	Bagging	RF		Single	Bagging	RF
B	1	5000	5000		1	5000	5000
J_{try}	9	9	3		73	73	9
J		9				73	
# of crises		103				103	

Notes: Dependent variable: two-year horizon before crisis. Restricted Selection: Loans (gap), Loans (gr), Foreign Liabilities (gap)(glo), LT Interest Rate (gap)(glo), GDP (gap)(glo), Inflation, Exchange Rate (gap), Reserves (gap), GDP (gr)(glo). Many Predictors: see table 5.7. For single tree: out-of-sample mean AUC- and confidence band estimates are based on Monte Carlo Cross-Validation (see Picard and Cook, 1984; Arlot, Celisse et al., 2010); 100 MC-draws of training (63,2%) - test (36,8%) data partitions. For ensembles: out-of-sample AUC-estimates (and confidence intervals) are based on out-of-bag (OOB)-data (see Breiman, 1996*b*). N number observations. J number of predictors under analysis. J_{try} number of predictors randomly selected and considered as a splitting variable at each recursive partitioning step. B number of trees. Specification table: If only the bagging column has an entry this means all models share the same specification. § H_0: $AUC_{many} - AUC_{restricted} = 0$. **Bold** H_0: $AUC - AUC_{logitFE\&IA}(= 0.65) = 0$. * H_0: $AUC_{Q4} - AUC_{quarterly} = 0$. All tests at the 5% significance level. Logit specification: restricted variable selection + interaction terms in table 2 (main text) (excluding terms with public debt) + country fixed effects.

Serial correlation- and cross-sectional correlation

The paper makes use of macroeconomic panel data. Serial and cross-sectinal correlation of macroeconomic predictors could induce correlated crisis probability estimates. This could bias estimates of confidence bands and hypothesis tests. To ensure that the results are robust to serial and cross-sectional correlation this section replicates the paper's main results on the basis of various robustified confidence bands.

1. Robustified AUC confidence bands for serially dependent data are calculated according to the recent contribution by Lahiri and Yang (forthcoming). These confidence bands are sligthly wider, but generally close to the ones reported in the paper (e.g. Lahiri & Yang: 0.84-0.92 vs. conventional: 0.85-0.91 for the AUC of the favorite random forest model on the long-run dataset).

2. It is possible to calculate AUC confidence bands on the basis of bootstrap samples that reflect the temporal and cross-sectional structure of the data. In particular, cross-sectional resampling (see Kapetanios, 2008) and temporal resampling with a block structure are carried out, in order to check the robustness of the paper's main results. The block size for the temporal resampling is set to $T^{1/4}$, as suggested by e.g. Andrews (2002) and Lahiri (2003). Table 5.11 shows the results for the cross-sectional-, temporal- and the two double-resampling schemes (all defined as in Kapetanios, 2008) for the long-run dataset. The 95% - confidence bands are somewhat wider, but the main results hold; for all bagging- and random forest-models the AUC significantly differs from 0.5. Furthermore, the models with many predictors always have an significantly higher AUC than the models based on only few predictors.

Table 5.11: *$\mathcal{CT}$-EWS: Long-run 1870-2012 Sample, Robust 95%-CI*

	Restricted Selection			**Many Predictors**		
	low	AUC	up	low	AUC	up
			Cross-sectional resampling			
Bagging	0.69	0.77	0.83	0.83	0.87 §	0.93
RF	0.71	0.79	0.86	0.82	0.88 §	0.92
			Temporal resampling			
Bagging	0.72	0.77	0.81	0.83	0.87 §	0.91
RF	0.75	0.79	0.82	0.85	0.88 §	0.92
			Cross-sectional/Temporal resampling			
Bagging	0.71	0.77	0.83	0.89	0.87 §	0.96
RF	0.75	0.79	0.87	0.86	0.88 §	0.95
			Temporal/Cross-sectional resampling			
Bagging	0.73	0.77	0.86	0.83	0.87 §	0.94
RF	0.59	0.79	0.80	0.79	0.88 §	0.94

Notes: 95% bootstrap confidence bands (5000-fold bootstrap). low: lower band. up: upper band. § H_0: $AUC_{many} - AUC_{restricted} > 0$. Restricted Selection: Loans/GDP (gap), Public Debt/GDP (gap), Narrow Money/GDP (gap), LT Interest Rate, GDP (gr), Inflation, Exchange Rate (gap), Loans/GDP, Public Debt/GDP, LT Interest Rate (n). Many Predictors: see table A1 in the data appendix. Out-of-sample *AUC*-estimates (and confidence intervals) are based on out-of-bag (OOB)-data (see Breiman, 1996*b*).

Different Crisis Horizons

Up to this point in the analysis, all models were trained to correctly identify the 2-year horizon before a banking crisis occurs. If however, next year's crisis risk is of particular concern, then a 1-year crisis horizon would be more desirable. In other cases, a 3-year crisis horizon might be preferred. I therefore estimate the $\mathcal{RF}$ EWS for 1- and 3-year crisis horizons as well. Generally, AUCs for the 1-year horizon are significantly lower than for the 2-year horizon, while the AUCs for the 3-year horizons are not statistically-speaking significantly different from those for the 2-year horizons.

Table 5.12 illustrates the results. The 1- and 3-year horizon AUC estimates for the long-run sample are displayed in the first two columns. For the 2-year horizon case, the mean AUC estimate was 0.88 (see table 3). The mean AUC estimate for the 1-year horizon (AUC=0.78) is lower than that. On the other hand, the 3-year horizon mean AUC estimate (AUC=0.89) is almost identical to the 2-year horizon estimate. Thus it is harder to assess whether there will be a crisis next year than to assess whether there will be a crisis within the next two or three years.

The results for the post-1970 samples lead to the same conclusion. As regards the annual post-1970 sample, the 1-year horizon AUC estimate (AUC=0.75) again falls by 0.06 compared to the 2-year horizon estimate (AUC=0.81) (see table 4). However, the 3-year horizon AUC estimate of 0.88 exceeds the corresponding 2-year horizon estimate by 0.07.

Finally, the 1-year horizon AUC estimate for the quarterly post-1970 sample (AUC=0.93) is somewhat lower than that for the 2-year horizon (AUC=0.95) (see table 5.9). The 3-year horizon AUC estimate is 0.96 – close to the 2-year horizon estimate.

To sum up, while the AUC estimates for the 3-year horizon are generally very close to those for the 2-year horizon, the AUC estimates for the 1-year horizon are significantly lower. As a results, it is harder to assess whether there will be a crisis next year, than to assess whether there will be a crisis within the next few years. On a more general note: The fact that the data allowed the $\mathcal{RF}$ algorithm to better discern the 3-year crisis horizon from all other observations than the 1-year horizon did, conforms to accounts which picture banking crisis risks as building up slowly over time. At the same time, the actual crisis realization is less determinate – usually triggered by a shock, which may or may not occur in any particular year.

Table 5.12: *Different Crisis Horizons*

	1-year horizon Long-run sample yearly	3-year horizon Long-run sample yearly	1-year horizon Post-1970 sample yearly	3-year horizon Post-1970 sample yearly	1-year horizon Post-1970 sample quarterly	3-year horizon Post-1970 sample quarterly
AUC	0.79 §	0.89	0.75 §	0.88	0.93 §	0.96
95%-CI	[0.73,0.85]	[0.87,0.91]	[0.7,0.79]	[0.86,0.9]	[0.92,0.94]	[0.95,0.96]
N	1742	1742	4189	4189	19061	19061
B	5000	5000	5000	5000	5000	5000
J_{try}	9	9	8	8	9	9
J	76	76	70	70	73	73
# of crises	70	70	100	100	102	102

Notes: Random forest results. Predictors: see tables 5.5, 5.6 and 5.7. Out-of-sample AUC-estimates (and confidence intervals) based on out-of-bag (OOB)-data (see Breiman, 1996*b*). N number observations. J number of predictors under analysis. J_{try} number of predictors randomly selected and considered as a splitting variable at each recursive partitioning step. B number of trees. Specification table: If only the bagging column has an entry this means all models share the same specification. § H_0: $AUC_{1/3-years} = AUC_{2-years}$

Boosting

Boosting is a relative to the CTE family. It shares many of CTE family characteristics and thus is interesting to look at in the context of banking crisis forecasting. Boosted classification trees can be described as a forest with directed tree growth: In the estimation of each new tree, particular weight is put on the correct classification of those observations which have been misclassified by the aggregate of all previously estimated trees (for a comprehensive introduction to boosting see Haste, Tibshirani and Friedman, 2013, chapter 10). As a tree-based method, tree-boosting principally features many of the properties which make CTEs fit for banking crisis forecasting. This, and their exceptional track record is reason enough to check what their crisis forecasting performance is like. In particular, a *stochastic gradient boosting machine* that is based on many predictors is applied. As regards the parameter specification, standard recommendations prevalent in the literature are followed (see Friedman, 2002; Buehlmann, 2006).

Columns one to three in table 5.13 display the results for the three samples. The AUC estimates range from 0.75 to 0.84. This places boosting somewhere between a single classification tree and bagging. Why does boosting stay behind the $\mathcal{F}$- and $\mathcal{RF}$ EWS? A likely explanation is the vulnerability of boosting algorithms to noisy data (Long and Servedio, 2010). In putting extra weight on the correct classification of observations that are hard to classify, boosting often ends up giving undue weight to datapoints that are merely noisy. The level of noise in macroeconomic data and in particular, the crisis dummies, should be expected to constrain the performance of boosting algorithms. Hence, when it comes to forecasting banking crises the $\mathcal{F}$- and $\mathcal{RF}$ EWS are preferable.

Table 5.13: *Tree Boosting*

	Long-run sample yearly	Post-1970 sample yearly	Post-1970 sample quarterly
AUC	0.78 §	0.75 §	0.84 §
95%-CI	[0.71,0.85]	[0.7,0.81]	[0.82,0.86]
N	1742	4189	19061
B	5000	5000	5000
J	76	70	73
η	0.5	0.5	0.5
ν	0.1	0.1	0.1
# of crises	70	100	102

Notes: Dependent variable: two-year horizon before crisis. Predictors: see tables 5.5, 5.6 and 5.7. Out-of-sample AUC-estimates (and confidence intervals) based on Monte Carlo Cross-Validation (see Picard and Cook, 1984; Arlot, Celisse et al., 2010) – 100 MC-draws of training (63,2%) - test (36,8%) data partitions. N number observations. J number of predictors under analysis. B number of trees. η random fraction of observations in training data that are used to estimate each tree. ν shrinkage parameter indicating the weight given to each new tree. § H_0: $AUC_{Boosting} = AUC_{RF}$.

5.A.4. Literature Review

Table 5.14: *Banking Crises and Variable Selection*

Publication	**Method**	Domestic		External		Financial				Fiscal
		GDP	CPI	CA	ER	Bank Assets	Money	Stock Prices	Interest Rates	Public Debt
Sachs, Tornell and A. (1996)	OLS	(/GDP gap)	-	(/GDP)	(rer gap)	(/GDP gap)	-	-	-	-
Caprio and Klingebiel (1996)	Frequency	(r gap)	-	-	-	(r gap)	-	-	-	-
Brenda González-Hermosillo et al. (1997)	Logit	-	-	-	(n gr)	(r) (/GDP)	-	-	(r)	-
Demirgüç-Kunt and Detragiache (1998)	Logit	(r gr)	(gr)	-	(n gr)	(/GDP) (r gr)	(r)	-	-	-
Detragiache and Demirgüc-Kunt (1998)	Logit	(r gr)	(gr)	-	(n gr)	(r) (/GDP) (r gr)	(r)	-	(r)	-
Eichengreen and Rose (1998)	Probit	(gr) (r gr glo)	-	(/GDP)	(rer)	(gr)	-	-	(glo)	(gap)
Hardy and Pazarbasioglu (1998)	Logit	(r gr)	(gr)	-	(rer gr)	(/GDP gr)	(/GDP gr)	-	(r)	-
IMF (1998)	Event Analysis	(r gr)	(gr)	(/GDP)	(n gr) (rer)	(/GDP)	(r)	(gr)	-	(gap /GDP)
Kaminsky (1998)	Signals	(r)	-	-	(rer gap)	(/GDP)	(r) (r gap)	(n)	(r) (r glo)	-
Brüggemann and Linne (1999)	Signals	(gr)	-	-	(gr rer)	(gr /GDP)	(gr)	-	(r)	(r gr)
Gourinchas, Valdes and Landerretche (1999)	Descriptives	(r) (gap)	(gr)	(/GDP)	(rer gap)	(/GDP gap)	-	-	(n) (r glo)	(/GDP gap)
Gonzalez-Hermosillo (1999)	Logit FE	(r gr)	(n)	-	(n gr)	(r) (/GDP)	-	-	(r) (r diff)	-
Hutchison and McDill (1999)	Signals	(r gr)	(gr)	-	(n gr)	(r gr)	(r)	(gr)	(n gr) (r gr)	(gap)

Continued on next page

Publication	Method	Domestic		External		Financial				Fiscal
		GDP	CPI	CA	ER	Bank Assets	Money	Stock Prices	Interest Rates	Public Debt
Kaminsky and Reinhart (1999)	Signals	(gr)	-	(r)	(rer gap)	(/GDP)	(r) (r gap)	(gr)	(r) (r diff)	-
Lindgren (1999)	Frequency	-	(gr)	(gap /GDP)	-	(/GDP) (r gr)	-	(/GDP)	-	(/GDP gap) (/GDP)
Rossi (1999)	Logit, FE	(r) (r gr)	(gr)	-	-	(r gr) (/GDP)	-	-	(r)	-
Demirguc and Detragiache (2000)	Logit	(r gr)	(gr)	-	(gr)	(r gr)	(r)	-	-	-
Glick and Hutchison (2000)	Signals Probit	(r gr)	(gr)	-	(gr)	-	-	-	-	-
Hawkins and Klau (2000)	Indices	-	-	-	-	(/GDP gr)	(/GDP gap)	-	(r)	-
Honohan (2000)	Mean comp.	-	-	-	-	(r) (gr)	-	-	-	(gap)
Goldstein, Kaminsky and Reinhart (2000)	Signals	(r gr)	-	(gr)	(rer gap)	(/GDP gr)	(r gap) (r gr) (gr)	(gr)	(r) (diff)	(/GDP) (gr) (gap /GDP)
Bordo et al. (2001)	Logit	(r) (r gr)	(gr)	-	-	-	(r)	-	-	(r gap)
Borio and Lowe (2002)	Signals	-	-	-	(r gap)	(/GDP gap)	-	(r gap)	-	-
Eichengreen and Arteta (2002)	Probit	(gr) (r gr glo)	-	(/GDP)	(rer gap)	(gr)	-	-	(glo)	(gr /GDP)
Hutchison (2002)	Probit	(r)	(gr)	-	(gr)	-	-	-	-	-
Mendis (2002)	Logit FE IA	(r gr)	(gr)	-	(rer)	(/GDP)	(r gr)	-	(n)	(/GDP gap)
Borio and Lowe (2004)	Signals	(r gap)	-	-	-	(/GDP gap)	(/GDP gap)	(r gap)	-	-
Demirguc-Kunt and Detragiache (2005)	Logit	(r gr)	(gr)	-	(n gr)	(/GDP) (r gr)	(r)	-	-	-
Davis and Karim (2008*a*)	Signals Logit	(gr) (r gr)	(gr)	(r)	(rer gap) (n gr)	(/GDP) (/GDP) (r gr)	(r) (r gap)	(gr)	(r) (r diff)	-
Davis and Karim (2008*b*)	Logit, $\mathcal{CT}$	(r gr)	(gr)	-	(n gr)	(/GDP) (r gr)	(r)	-	(r)	-

Continued on next page

Publication	**Method**	Domestic		External		Financial				Fiscal
		GDP	CPI	CA	ER	Bank Assets	Money	Stock Prices	Interest Rates	Public Debt
Borio and Drehmann (2009)	Signals	-	-	-	-	(/GDP gap)	-	(r gap)	-	-
Barrell et al. (2010)	Logit	GDP (r gr)	CPI (gr)	-	-	(r)	(r)	-	(r)	(gr /GDP)
Schularick and Taylor (2012)	OLS Logit, FE	-	(gr)	-	-	(r gr) (r gap) (/GDP)	(r gr)	(r) (r gr)	(r) (n)	-
Jordà, Schularick and Taylor (2011)	Logit	(r)	(gr)	(/GDP) (gr /GDP)	-	(gr /GDP)	-	(r gr)	(r) (n)	-
Alessi and Detken (2011)	Signals	(r gap) (r gr)	(gr) (gap)	-	(rer gap) (rer gr)	(r glo gap) (/GDP gap) (r gr) (r gap)	(r gap) (r gap glo) (r gr) (/GDP gap)	(r gap) (/GDP gap)	(n gap) (n) (glo gap) (r gap) (r) (r glo)	-
Casu, Clare and Saleh (2011)	Signals	-	-	-	-	(gr gap) (/GDP gap) (n gap)	-	(n gap)	(n gap)	-
Duttagupta and Cashin (2011)	$\mathcal{CT}$	(r gr)	(gr)	(r)	(n gr)	(r gr)	(r)	-	(r)	-
Gourinchas and Obstfeld (2012)	Logit	(r gap)	-	(/GDP)	(rer gap)	(/GDP)	-	-	-	(/GDP)
Drehmann and Juselius (2012)	Signals	-	-	-	-	(/GDP gap)	-	-	(/GDP)	-
Frankel and Saravelos (2012)	OLS Probit	(r) (r gr) (r gr gap)	(gr gap)	(r) (/GDP)	(rer gap)	(gr /GDP)	(r gap)	(r gap)	(r)	-
Eicher, Christofides and Papageorgiou (2012)	BMA	(r) (r gr) (r gr gap)	(gr gap)	(r) (/GDP)	(rer gap)	(gr /GDP)	(r gap)	(r gap)	(r)	-
Hahm, Shin and Shin (2012)	Probit RE	(r gr glo)	(gr)	-	-	(/GDP gap)	(r)	-	(glo)	-
Drehmann (2013)	Signals	-	-	-	-	(/GDP gap)	-	-	-	-
Jordà (2013)	Logit IA, FE	-	-	(/GDP gap)	-	(/GDP gap)	-	-	(n)	(/GDP gap)
Drehmann and Juselius (2013)	Signals	(r gr)	-	-	-	(r gr) (/GDP gap)	(r)	(n gr) (gap)	(r)	-

Notes: (r) real; (n) nominal; (gr) growth; (glo) global GDP-weighted average; (gap) percentage deviation from (one-sided) HP-trend (λ = 1600); $\mathcal{CT}$ Classification Tree; IA Interaction Terms; FE Fixed Effects; RE Random Effects; BMA Bayesian Model Averaging; MIMIC Multiple Indicator Multiple Cause Model. There is an overlap between 3rd generation currency crises and banking crises, also termed twin crises. Publications on these 3rd generation currency crises have been included in the table if they exhibit a focus on the banking crisis aspect. The table does not list all variables the authors use in each publication. Instead it maps the variables into nine variable categories. The focus is on macroeconomic predictors (see Gavin and Hausmann, 1996) while microeconomic, (e.g. González-Hermosillo, 1996; Caprio and Klingebiel, 1996; Gonzalez-Hermosillo, 1999), political or institutional (see Acemoglu et al., 2003) factors are not listed in the table. Also, interaction terms between any two variables included in the table are not made explicit. In some cases the mapping is rather coarse. For example, non-core liabilities (Hahm, Shin and Shin, 2012) are listed as a real monetary variable in table 5.14. The main aim of the table is to give an impression of the variance and selectivity *in* - and not an exact overview *of* - variable selections in the literature on banking crises.

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