

Essays in International Macroeconomics

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Contents

List of Figures	vi
List of Tables	viii
1 Introduction	1
2 When Do Fixed Exchange Rate Work? Evidence from the Gold Standard	3
2.1 Introduction	3
2.2 Data	6
2.2.1 Effective exchange rates	7
2.2.2 Gold cover ratios	7
2.2.3 Sectoral shares, prices and exports	8
2.3 Stylized facts	8
2.4 A model of the Gold Standard	13
2.4.1 Households	13
2.4.2 Firms	16
2.4.3 Equilibrium	16
2.4.4 Monetary policy and gold flows	17
2.5 Bayesian estimation	19
2.5.1 Observables	20
2.5.2 Calibration	20
2.5.3 Prior distribution	22
2.5.4 Posterior distribution	26
2.5.5 Model evaluation	27
2.6 Counterfactual analysis	30
2.7 Sectoral structure, price level flexibility and external adjustment	32
2.7.1 Sectoral structure and price level flexibility	32

2.7.2	Terms of trade vs. local prices	36
2.7.3	Engel decomposition	38
2.8	Conclusion	40
2.A	Data appendix	42
2.A.1	An annual macrodataset on 14 Gold Standard economies, 1870-1913	42
2.A.2	Migration data	47
2.A.3	Sectoral price data	50
2.A.4	Sectoral exports	51
2.A.5	Primary sector shares	66
2.A.6	Real effective exchange rates	67
2.A.7	Gold cover ratios	68
2.A.8	Adjustment periods	70
2.B	Model appendix	72
2.B.1	Nonlinear model	72
2.B.2	Steady state	76
2.B.3	Log-linearized model	77
2.B.4	An extended model with sectoral structure	81
2.C	Additional results	89
2.C.1	Alternative adjustment periods	89
2.C.2	Contemporaneous correlations	92
2.C.3	Additional model results	94
3	Sovereign Default Risk and the Role of International Transfers	111
3.1	Introduction	111
3.2	Theoretical framework	115
3.2.1	The baseline model	115
3.2.2	The optimal risk sharing scheme	122
3.2.3	The standby facility	126
3.3	Quantitative analysis	130
3.3.1	Calibration	130
3.3.2	Quantitative performance of the baseline model	132
3.3.3	Impact of the optimal risk sharing scheme and the standby facility	136
3.4	Conclusion	140
4	Sovereign Risk Spillover and Monetary Policy in a Currency Union	141
4.1	Introduction	141
4.2	The model framework	146

4.3	Sovereign risk spillover and shock transmissions	152
4.3.1	Log-linearized structural relations	153
4.3.2	Model calibration	155
4.3.3	Maturity	158
4.3.4	Sovereign risk spillover and shock transmissions	159
4.4	Optimal monetary policy	163
4.4.1	Optimal monetary policy in a simplified model	164
4.4.2	Numerical analysis	167
4.5	Conclusion	172
4.A	Appendix	173
4.A.1	Nonlinear structural equations	173
4.A.2	Efficient allocation	175
4.A.3	Steady state	176
4.A.4	Approximate equilibrium	178
4.A.5	Welfare function	180
4.A.6	Optimal target criterion in the simplified model	184
4.A.7	Coefficients for the adjusted target criterion	185
4.A.8	Impulse responses under the Taylor rule	188
4.A.9	Impulse responses under alternative monetary policies	192
	References	195

List of Figures

2.1	Average GDP- and CA/GDP-behavior around major CA/GDP-reversals .	5
2.2	Prices, migration and monetary policy after major reversals in the CA/GDP-ratio	10
2.3	Sectoral prices and sectoral exports after major CA/GDP-reversals relative to non-reversals	34
2.4	Sectoral adjustment after major reversals in the CA/GDP-ratio	35
2.5	Terms of trade vs. local prices after major reversals in the CA/GDP-ratio	36
2.6	Immigration rates: migration data vs. population and vital data	50
2.7	Price level: GDP deflator vs. weighted average of sectoral prices	52
2.8	Primary sector shares	66
2.9	REERs within the Gold Standard	67
2.10	Gold cover ratios, narrow	68
2.11	Gold cover ratios, broad	69
2.12	CA/GDP within the Gold Standard	70
2.13	CA/GDP within the euro area	71
2.14	CA/GDP within the Gold Standard	89
2.15	Alternative adjustment periods: prices, migration and monetary policy . .	90
2.16	Alternative adjustment periods: sectoral prices and sectoral exports . . .	91
2.17	Alternative adjustment periods: terms of trade vs. local prices	91
2.18	Alternative adjustment periods: sectoral adjustment	91
2.19	Observables and smoothed variables	94
2.21	(Auto-)correlations	97
2.22	Baseline and counterfactual impulse responses	103
3.1	Model dynamics around default events	135
4.1	Determinants of government debt level and the bond maturity	158
4.2	Impulse responses under the Taylor rule: cost-push shocks	160
4.3	Impulse responses under the Taylor rule: monetary policy shock	161
4.4	Impulse responses under the Taylor rule: default probability shocks	162
4.5	Impulse responses under alternative monetary policies: cost-push shock .	168

4.6	Impulse responses under alternative monetary policies: default probability shock	169
4.7	Impulse responses under alternative monetary policies and short-term government debt: default probability shock	171
4.8	Impulse responses under the Taylor rule	188
4.9	Impulse responses under alternative monetary policies	192

List of Tables

2.1	Calibrated parameters	21
2.2	Prior distribution	25
2.3	Posterior distribution	28
2.4	Counterfactual per capita output volatilities	31
2.5	Sectoral structure, export composition and price volatilities	33
2.6	Local prices, terms of trade and the trade balance	38
2.7	Engel decomposition	39
2.8	Within Gold Standard trade shares	53
2.9	Sectoral price data	54
2.10	Migration data	57
2.11	Export categories	59
2.12	Correlation between external adjustments, sectoral size and prices	88
2.13	Prices, migration and monetary policy correlation with the trade balance	92
2.14	Correlation between external adjustment, sectoral prices and sectoral exports	92
2.15	Correlation between external adjustment, export prices, import prices and local prices	93
2.16	Correlation between external adjustment and sectoral adjustment	93
2.17	Forecast error variance decomposition	100
2.18	Counterfactual volatility	106
2.19	Counterfactual volatility	109
3.1	Government's debt decision	127
3.2	Calibration	132
3.3	Statistical moments: model vs. data	134
3.4	Statistical moment: baseline model vs. insurance schemes	138
4.1	Calibration	157

1

Introduction

What are the conditions for a well-functioning currency union? Since the 1960s', there has been a long stream of literature dedicated to this question. Through studying the historical fixed exchange rate regime of the Gold Standard (chapter 2) and the modern day euro area (chapters 3 and 4), this thesis aims to add to the understanding of the economics of currency unions.

CHAPTER 2 “When Do Fixed Exchange Rate Work? Evidence from the Gold Standard” examines external adjustments within a currency union. In particular, my co-author Felix Ward and I look at the historical circumstances of a fixed exchange rate regime that worked smoothly – the 1880-1913 Gold Standard. External adjustment under the Gold Standard was associated with few if any, output costs. How did countries on the Gold Standard equilibrate so smoothly despite inflexible exchange rates that were pegged to gold? To answer this question, we build and estimate an open economy model of the Gold Standard. This allows us to quantitatively assess the relative importance of three prominent channels of external adjustment: flexible prices, international migration, and monetary policy. Our first finding is that the output resilience of Gold Standard members was primarily a consequence of flexible prices. When hit by a shock, quickly adjusting prices induced import- and export responses that stabilized output. Neither restrictions on migration, nor the elimination of countercyclical monetary policy would have given rise to substantially higher output-volatility. Our second finding is that price flexibility was predicated on a historical contingency: namely large primary sectors, whose flexibly priced products dominated the export booms that stabilized output during major external adjustments.

CHAPTER 3 “Sovereign Default Risk and the Role of International Transfers” asks what is the impact of interregional risk sharing arrangements when countries are afflicted

with sovereign default risk. This is of particular interest in the setup of currency unions, where countries give up the exchange rate as a tool for business cycle stabilization. I introduce a sovereign default model in which regional sovereign default risk affects private sector financing costs and the linkage between public and private sector financing costs can exacerbate economic downturns. In this context, the benefit of international risk sharing comes in two dimensions. First, it helps to smooth consumption – the traditional channel of insurance. More importantly, by ameliorating large recessions, international risk sharing reduces the asymmetric impact of productivity shocks and raises average output level. Quantitative analysis shows that most of the welfare benefits that are obtainable from the optimal risk sharing arrangement can be reaped by a standby facility that is easy to implement. This finding is of policy relevance because whenever interregional risk sharing schemes are discussed between sovereign nation states, the willingness to part with fiscal autonomy is often severely limited.

In CHAPTER 4 “Sovereign Risk Spillover and Monetary Policy in a Currency Union”, I investigate the pass-through of sovereign default risk to the private sector financing condition from a different angle. In particular, I use a two-region currency union model to examine how the spillover affects shock propagation and optimal monetary policy. On the one hand, an increase in a region’s sovereign risk premium raises the regional private sector credit spread, depresses inflation and tax revenue and further worsens the fiscal position. On the other hand, it also triggers changes in the policy interest rate. The net impact depends on the maturity of the government debt. When calibrated to the euro area and taken into account the average long maturity of government debt, the impact of the sovereign risk spillover on shock propagation is negligible. This is also reflected in optimal monetary policy. For the euro area, optimal monetary policy is well approximated by a simple target criterion that describes the optimal relation between output and inflation as derived from a basic New Keynesian model without sovereign risk and credit spreads. This continues to be the case even when there are cross-regional differences in their exposure to sovereign default risks. If government debts are short-term, however, the spillover considerably affects shock transmission and optimal monetary policy requires a stronger immediate shock-response.

2

When Do Fixed Exchange Rate Work? Evidence from the Gold Standard

Joint with Felix Ward

2.1 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 et al., 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 et al., 2014; Eichengreen and Flandreau, 2016) 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

2.1. Introduction

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.

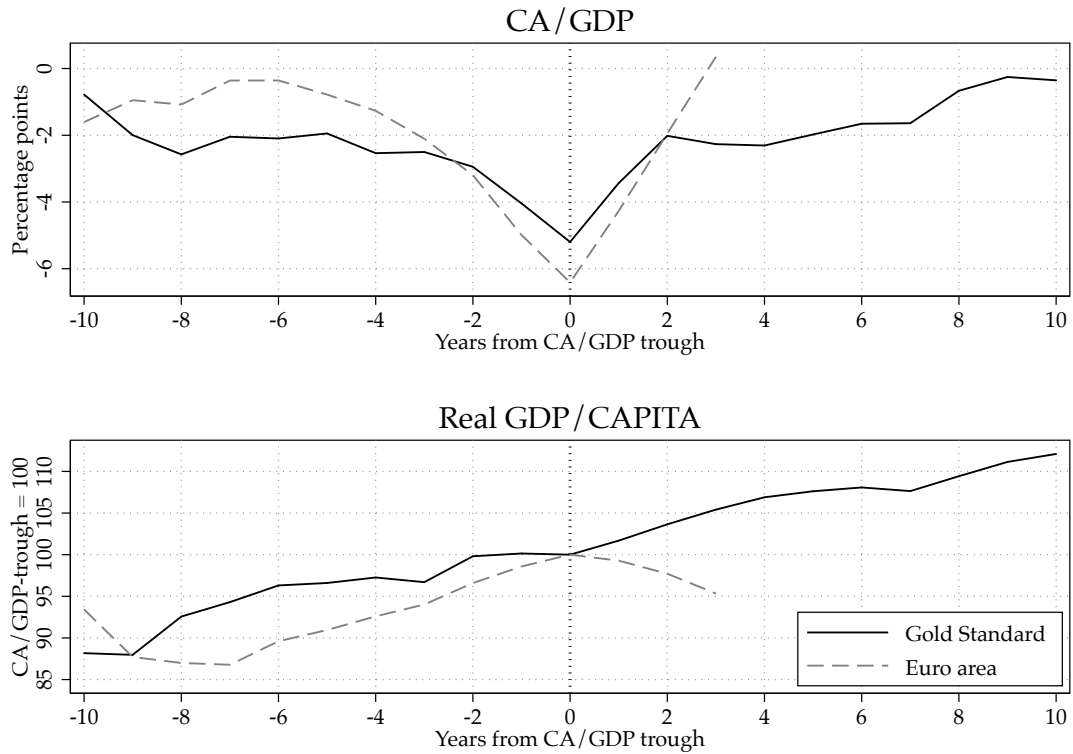
A study of external adjustment under the Gold Standard is particularly interesting in light of the often painful adjustment experiences in fixed exchange rate regimes today. Figure 2.1, for example, contrasts external adjustment under the Gold Standard with that in the euro area:¹ Under the Gold Standard 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,

¹CA/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 ± 10 -year window. For the EZ a ± 8 -year window was chosen and border conditions were weakened because of the shorter sample length.

2.1. Introduction

Figure 2.1: 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.

Section 2.3 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 2.4 and 2.5 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 2.6. Section

2.2. Data

2.7 substantiates our findings from the 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 2.8 then concludes our analysis.

2.2 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 Appendix 2.A.1. Further data descriptions, as well as reliability and validation checks for the sectoral data and migration series can be found in Appendices 2.A.4, 2.A.2 and 2.A.3.

2.2. Data

2.2.1 Effective exchange rates

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

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

where $w_{i,j,t}$ is the bilateral trade weight. The real exchange rate is the product of the nominal exchange rate² and the ratio of consumer prices, $REER_{i,j,t} = NER_{i,j,t} \frac{CPI_{i,t}}{CPI_{j,t}}$.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 nominal effective exchange rates (NEER) and foreign effective consumer price indices as trade-weighted geometric averages. The final REER series are displayed in Figure 2.9 in Appendix 2.A.6.

2.2.2 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,

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

³This 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 inverse of the REER calculated on the basis of exchange rates quoted in quantity notation.

⁴We 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.

⁵This 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 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.

2.3. Stylized facts

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 2.10 and 2.11 in Appendix 2.A.7.

2.2.3 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 Appendices 2.A.4 and 2.A.3. The sectoral value-added share data come from Buera and Kaboski (2012).

2.3 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) 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 2.14 in Appendix 2.A.8).⁷

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

⁷As 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 Appendix 2.C.1).

2.3. Stylized facts

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

$$D_h(x_{i,t+h}, A_{i,t}) = E_{i,t}(x_{i,t+h} | A_{i,t} = 1) - E_{i,t}(x_{i,t+h} | A_{i,t} = 0), \quad h = 1, \dots, H \quad (2.1)$$

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 $D_h(x_{i,t+h}, A_{i,t})$, $h = 1, \dots, H$ 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:

$$\frac{x_{i,t+h} - x_{i,t}}{x_{i,t}} = \alpha_{i,h} + \beta_h A_{i,t} + u_{i,t+h}, \quad h = 1, \dots, H \quad (2.2)$$

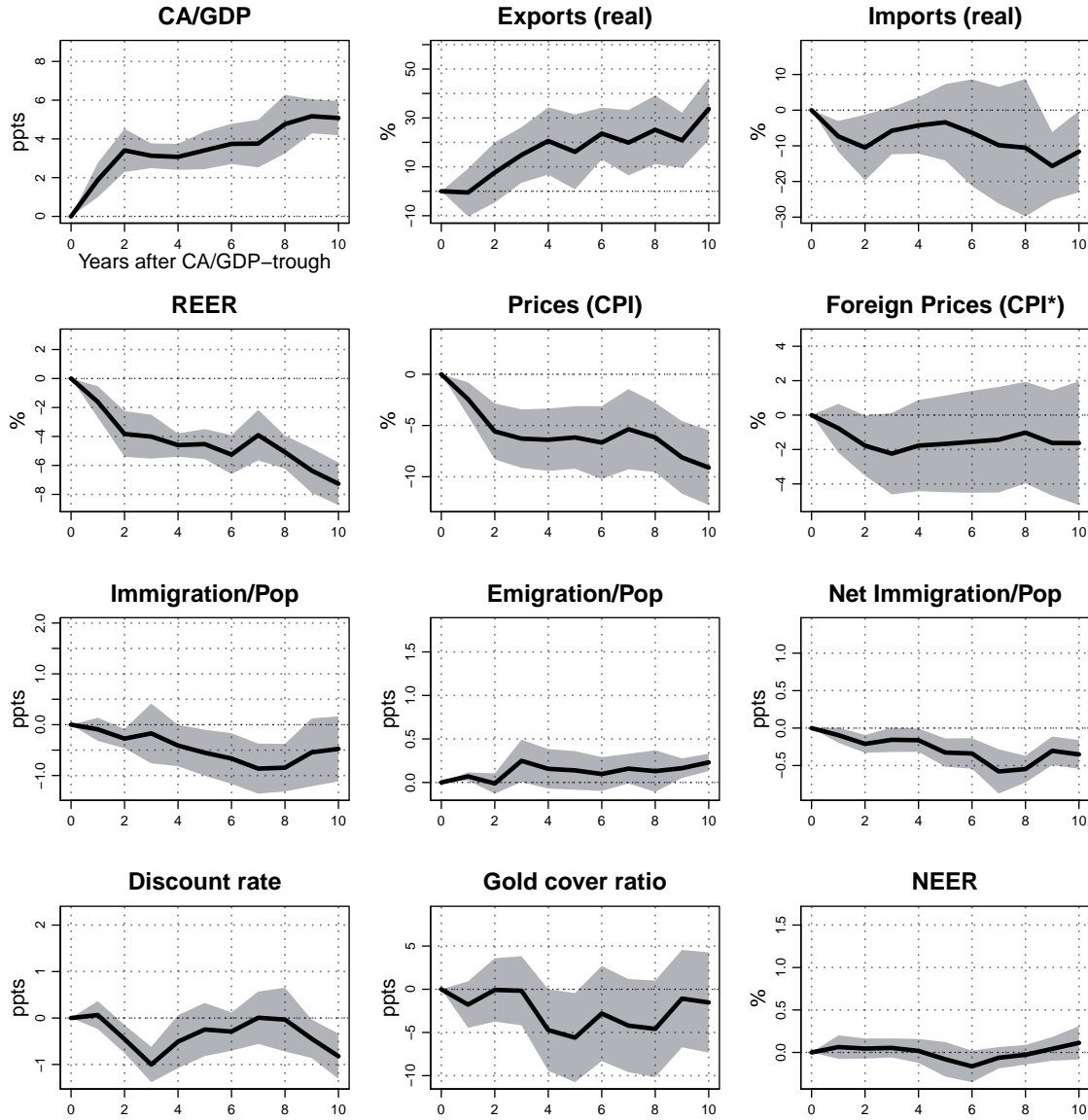
where α_i are country-fixed effects and $u_{i,t}$ is an error term. The $\{\beta_h\}_{h=1,\dots,H}$ in expression (2.2) allow us to sketch out the average behavior of macroeconomic aggregates over the H years following a major CA/GDP-trough. This will provide us with a set of stylized facts on how GS-member economies typically behaved during major adjustment phases in contrast to their behavior during “normal” times.⁸

The first row of Figure 2.2 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 2.2 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%.

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

2.3. Stylized facts

Figure 2.2: 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.

2.3. Stylized facts

How about migration? The third row of Figure 2.2 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 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 2.2 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

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

¹⁰This 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.

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

¹²In 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.

2.3. Stylized facts

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 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)). 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 2.2 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, 2016; Bazot et al., 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.

¹³This 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.

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

¹⁵The 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 2.13 in Appendix 2.C.2), as well as an alternative definition of CA/GDP troughs (see Figure 2.15 in Appendix 2.C.1).

2.4 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 2.B.1.

2.4.1 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 et al. (1988) (GHH) form. The household maximizes its life time utility¹⁷

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

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: $c_{H,t} = \left(\left(\frac{1}{n} \right)^{\frac{1}{\mu}} \int_0^n c_{H,t}(j)^{\frac{\mu-1}{\mu}} dj \right)^{\frac{\mu}{\mu-1}}$ and $c_{F,t} = \left(\left(\frac{1}{1-n} \right)^{\frac{1}{\mu}} \int_n^1 c_{F,t}(j)^{\frac{\mu-1}{\mu}} dj \right)^{\frac{\mu}{\mu-1}}$, where j is the firm index and μ is the elasticity of substitution between goods produced in the same region. The

¹⁶The 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 Appendix 2.C.3.6).

¹⁷Schmitt-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.

2.4. A model of the Gold Standard

price indices for the H - and F -produced goods bundles are $P_{H,t} = \left[\frac{1}{n} \int_0^n P_{H,t}(j)^{1-\mu} dj \right]^{\frac{1}{1-\mu}}$ and $P_{F,t} = \left[\frac{1}{1-n} \int_n^1 P_{F,t}(j)^{1-\mu} dj \right]^{\frac{1}{1-\mu}}$. 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

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

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 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: $TR_t = \frac{n_t^*}{n_t} \frac{P_t^*}{e_t} \frac{K^*}{2} \left(\frac{B_{H,t}^i e_t}{P_t^*} - \bar{o}^* \right)^2$. 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

¹⁸While 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).

¹⁹See Diebold et al. (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.

²⁰We 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 2.B.2).

2.4. A model of the Gold Standard

migrate $\tau \in \{H \rightarrow H, H \rightarrow F, F \rightarrow H, F \rightarrow F\}$, where \rightarrow 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.

2.4.1.1 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

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

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

²¹Kennan 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.

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

²³Type 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 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).

2.4. A model of the Gold Standard

the population fraction that emigrates, \tilde{d}_t , equals the emigration probability, d_t .²⁴ The aggregate population in H , therefore, evolves according to²⁵

$$n_t = (1 - \tilde{d}_t) n_{t-1} + \tilde{d}_t^* n_{t-1}^*. \quad (2.3)$$

2.4.2 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 $\tilde{\kappa} = \frac{(1-\beta\theta)(1-\theta)}{\theta(1-\mu+\mu/\gamma)}$.²⁷

2.4.3 Equilibrium

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

$$\begin{aligned} 0 &= n_t B_{H,t} + n_t^* B_{H,t}^* \\ 0 &= n_t B_{F,t} + n_t^* B_{F,t}^* \\ y_t(j) &= n_t c_{H,t}(j) + n_t^* c_{H,t}^*(j), \quad j \in [0, n) \\ y_t^*(j) &= n_t c_{F,t}(j) + n_t^* c_{F,t}^*(j), \quad j \in [n, 1] \end{aligned}$$

²⁴While 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.

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

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

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

2.4. A model of the Gold Standard

$$n_t l_t = \int_0^n L_t(j) dj, \quad j \in [0, n)$$

$$n_t^* l_t^* = \int_n^1 L_t^*(j) dj, \quad j \in [n, 1]$$

2.4.4 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 Appendix 2.A.7). 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

²⁸For 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.

²⁹Here 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

2.4. A model of the Gold Standard

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

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

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

$$G_t = G_{t-1} + F(e_t) \exp(\epsilon_t^m), \quad (2.4)$$

$$F(\bar{e}) = 0, \quad \epsilon^e := \frac{\partial F}{\partial e_t} \geq 0$$

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 et al., 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.

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.

³⁰Here, 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.

³¹We 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.

2.5. Bayesian estimation

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.

2.5 Bayesian estimation

We loglinearize the model around its non-stochastic steady state (see Appendix 2.B.3) 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 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, 2016). 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

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

³³At that time, only Norway had a comparably high emigration rate with a similarly countercyclical pattern. Counterfactual simulation results for Norway are reported in Appendix 2.C.3.6. The results are in line with the conclusions drawn on the basis of the other three countries' estimation results.

³⁴The 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 Appendix 2.C.3.6. These results

2.5. Bayesian estimation

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.

2.5.1 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 population³⁵; 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 2.3). 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.

2.5.2 Calibration

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 2.1). 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 ,

lead to conclusions very similar to those we draw from the Belgian case.

³⁵Most 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.

³⁶This value is consistent with Jacks et al. (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).

2.5. Bayesian estimation

Table 2.1: 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
<i>United Kingdom</i>		
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
<i>Sweden</i>		
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
<i>Belgium</i>		
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.

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: 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

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

³⁸According to the datasets provided by Hills et al. (2015) and Piketty and Zucman (2014).

2.5. Bayesian estimation

(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 $\bar{d}n = \bar{d}^*n^*$.

2.5.3 Prior distribution

The prior distribution is selected according to the *endogenous prior* method introduced by Christiano et al. (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 2.2. 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; 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

³⁹Since 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.

⁴⁰The model's steady state for net foreign assets is determined due to migration (see Appendix 2.B.2).

⁴¹As in Christiano et al. (2011), we use the actual sample as our *pre-sample*.

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

2.5. Bayesian estimation

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 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 $\tilde{\kappa} = (1 - \beta\theta)(1 - \theta)/[1/\theta(1 - \mu + \mu/\gamma)]$. 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 et al., 2008; Chernyshoff et al., 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 $\tilde{\kappa}$ and $\tilde{\kappa}^*$, which gives almost equal prior weight to all but the most extreme values of the 0-1 range.

On the monetary side, following Benati (2008) and Fagan et al. (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

⁴³Note 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.

2.5. Bayesian estimation

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 countries might have wanted to keep their nominal exchange rates stable vis-à-vis the U.K. (see Morys, 2011) 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 et al. (2011) we calibrate the measurement errors' variance to 10% of the variance in the observables. As shown in Appendix 2.C.3.1, the data without measurement error very closely follow the original data.

⁴⁴The Bank of England decided upon its discount rate on a weekly basis (see Eichengreen et al., 1985).

⁴⁵Note 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.

⁴⁶The 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 2.2: Prior distribution

Description	Distribution	Mean	S.D.	Description	Distribution	Mean	S.D.				
<i>Utility parameters</i>				<i>Shock parameters</i>							
σ_c	Inverse EIS	Normal	1.50	0.35	ρ^a	Persistence, technology (H)	Beta	0.30	0.15		
σ_l	Inverse Frisch elasticity	Normal	2.00	0.75	ρ^{a*}	Persistence, technology (F)	Beta	0.30	0.15		
ϵ	Trade elasticity (H)	Normal	1.50	1.50	ρ^g	Persistence, markup (H)	Beta	0.30	0.15		
ϵ^*	Trade elasticity (F)	Normal	1.50	1.50	ρ^{g*}	Persistence, markup (F)	Beta	0.30	0.15		
<i>Migration parameters</i>				ρ^x				Persistence, money demand (H)	Beta	0.30	0.15
ψ	Migration sensitivity (H)	Normal	2.00	1.00	ρ^{x*}	Persistence, money demand (F)	Beta	0.30	0.15		
ψ^*	Migration sensitivity (F)	Normal	2.00	1.00	ρ^b	Persistence, risk premium (H)	Beta	0.30	0.15		
<i>Price parameters</i>				ρ^{b*}				Persistence, risk premium (F)	Beta	0.30	0.15
$\tilde{\kappa}$	Phillips curve slope (H)	Beta	0.50	0.28	ρ^m	Persistence, gold (H & F)	Beta	0.30	0.15		
$\tilde{\kappa}^*$	Phillips curve slope (F)	Beta	0.50	0.28	η^a	S.D., technology (H)	Inv. gamma	0.50	2.00		
<i>Gold flow parameters</i>				η^{a*}				S.D., technology (F)	Inv. gamma	0.50	2.00
ϵ^e	Gold flow due to exchange rate	Uniform	[0, 15]		η^g	S.D., markup (H)	Inv. gamma	0.50	2.00		
$\frac{\bar{G}}{\bar{G}^*}$	Relative gold stock	Inv. gamma	$\frac{n}{1-n}$	1.00	η^{g*}	S.D., markup (F)	Inv. gamma	0.50	2.00		
<i>Discount rate parameters</i>				η^x				S.D., money demand (H)	Inv. gamma	0.50	2.00
ρ	Discount rate persistence (H)	Beta	0.30	0.15	η^{x*}	S.D., money demand (F)	Inv. gamma	0.50	2.00		
Φ^y	Output coefficient (H)	Beta	1.00	0.56	η^b	S.D., risk premium (H)	Inv. gamma	0.50	2.00		
Φ^e	Exchange rate coefficient (H)	Beta	1.00	0.56	η^{b*}	S.D., risk premium (F)	Inv. gamma	0.50	2.00		
Φ^g	Cover ratio coefficient (H)	Beta	1.00	0.56	η^r	S.D., monetary policy (H)	Inv. gamma	0.10	2.00		
ρ^*	Discount rate persistence (F)	Beta	0.30	0.15	η^{r*}	S.D., monetary policy (F)	Inv. gamma	0.10	2.00		
Φ^{y*}	Output coefficient (F)	Beta	1.00	0.56	η^m	S.D., gold (H & F)	Inv. gamma	0.50	2.00		
Φ^{e*}	Exchange rate coefficient (F)	Beta	1.00	0.56	σ_{aa^*}	Correlation, technology	Beta	0.50	0.28		
Φ^{g*}	Cover ratio coefficient (F)	Beta	1.00	0.56							
<i>Other parameters</i>											
K	Portfolio adjustment costs	Inv. gamma	0.04	2.00							
v^r	Interest rate elasticity of money demand	Inv. gamma	0.10	0.03							

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.

2.5.4 Posterior distribution

Table 2.3 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 ($\Phi_{Taylor}^y = 0.5$). 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.

⁴⁷Between 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.

2.5.5 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 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 (2.4)). 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 2.21 in Appendix 2.C.3.2 show the correlations, including the 90% coverage percentiles for the stochastic simulations. The model fairly accurately represents the data’s correlation structure.

⁴⁸Per 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.

⁴⁹We 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 2.3: Posterior distribution

Description	U.K.			Sweden			Belgium			
	Mean	90% HPDI		Mean	90% HPDI		Mean	90% HPDI		
<i>Utility parameters</i>										
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
<i>Migration parameters</i>										
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
<i>Price parameters</i>										
$\tilde{\kappa}$	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
<i>Gold flow parameters</i>										
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
<i>Discount rate parameters</i>										
ρ	Discount rate persistence (H)	–	–	–	0.42	0.18	0.65	0.44	0.28	0.59
Φ^y	Output coefficient (H)	0.14	0.09	0.19	0.18	0.01	0.34	0.02	0.00	0.04
Φ^e	Exchange rate coefficient (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 coefficient (F)	0.04	0.00	0.09	0.16	0.00	0.33	0.06	0.00	0.13
Φ^{e*}	Exchange rate coefficient (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
<i>Other parameters</i>										
K	Foreign portfolio adjustment costs	0.24	0.01	0.45	0.09	0.02	0.17	0.53	0.34	0.72
v^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 2.3: Posterior distribution (continued)

Description	U.K.			Sweden			Belgium			
	Mean	90% HPDI		Mean	90% HPDI		Mean	90% HPDI		
<i>Shock parameters</i>										
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

Note: 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.

2.6 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 2.4 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

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

2.6. Counterfactual analysis

absolutely fixed exchange rate, while F – a much larger region than H – sets its discount rate as estimated.⁵¹ Column (4) in Table 2.4 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 short-run monetary policy could exert a non-negligible stabilizing influence (see Figure 2.22 in the Appendix). Such short-run dynamics get played down in Table 2.4, 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 2.4: Counterfactual per capita output volatilities

	Baseline model	Counterfactuals				
		Rigid prices	No migration	No independence	No migration, given rigid prices	No independence, given rigid prices
	(1)	(2)	(3)	(4)	(3 2)	(4 2)
<i>United Kingdom</i>	1.76	3.20 (81.50%)	1.75 (-0.89%)	1.82 (3.19%)	3.19 (-0.16%)	3.42 (7.03%)
<i>Sweden</i>	1.88	4.26 (126.77%)	1.87 (-0.20%)	1.90 (0.91%)	4.28 (0.46%)	4.38 (2.82%)
<i>Belgium</i>	0.94	2.29 (145.15%)	0.97 (3.77%)	0.93 (-0.19%)	2.29 (-0.01%)	2.29 (-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 2.4 does not support

⁵¹See Appendix 2.B.3 for details.

⁵²See 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.

2.7. Sectoral structure, price level flexibility and external adjustment

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.

2.7 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 how much during external adjustments? Was it really an increase in the export of flex-price goods that turned around the current account?

2.7.1 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 et al., 1990; Jacks et al., 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 2.5 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

⁵³The 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 et al., 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).

2.7. Sectoral structure, price level flexibility and external adjustment

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 2.5). 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).

Table 2.5: 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.

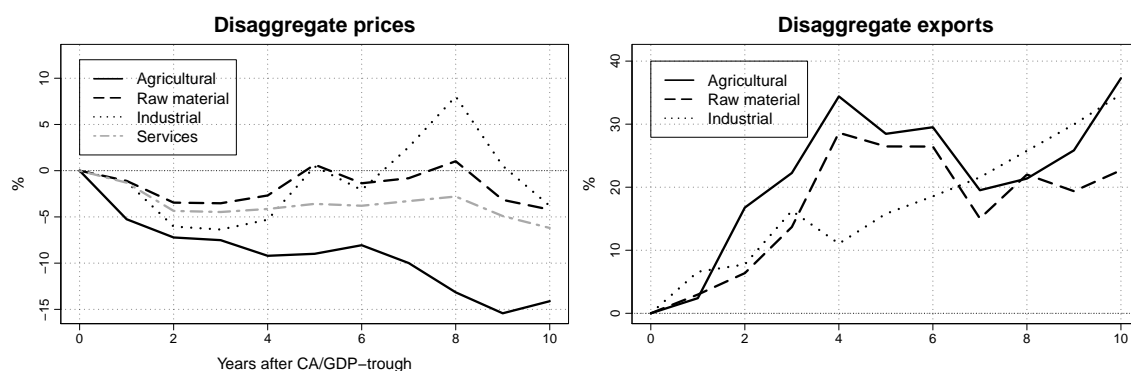
⁵⁴The high flexibility of agricultural prices has been linked to their supply and demand elasticities, with short-run supply being highly inelastic (Cairnes, 1873). Perishability and storability play a role in this, with less durable products generally exhibiting more flexible prices (Mills, 1927; Telser, 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).

⁵⁵This comes very close to figures by Aparicio et al. (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).

2.7. Sectoral structure, price level flexibility and external adjustment

A look at disaggregated nominal prices and real (CPI-deflated) exports confirms the crucial role agriculture played for external adjustment under the GS (see Figure 2.3). 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

Figure 2.3: 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.

Increasing primary good exports also left their mark on the adjusting economy's sectoral structure. Figure 2.4 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

⁵⁶In 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.

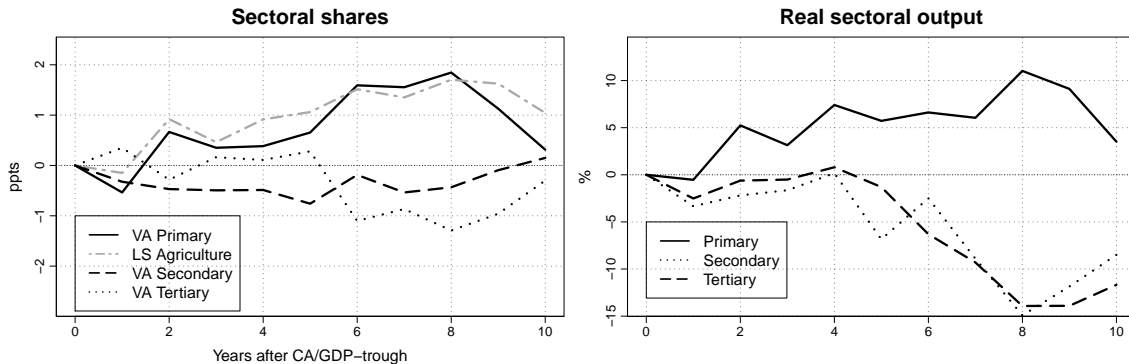
⁵⁷Note that while the sharp increase in agricultural exports is accompanied by an equally sharp fall in agricultural prices, this is not the case for raw materials. This possibly hints at differential price elasticities in the international demand for agricultural goods and raw materials.

⁵⁸This 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 2.14 in Appendix 2.C.2).

2.7. Sectoral structure, price level flexibility and external adjustment

(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

Figure 2.4: 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 ± 10 -year window. The number of CA/GDP-troughs thus identified is nine. VA – value added share. LS – labor share.

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

⁵⁹This relationship is robust to an alternative definition of major CA/GDP troughs (see Figure 2.18 in Appendix 2.C.1). It also is present outside of major adjustment periods, in the contemporaneous correlations of changes in the CA/GDP ratio with changes in the sectoral shares (see Table 2.16 in Appendix 2.C.2).

⁶⁰Note that large primary sector shares today are far less associated with benign external adjustments among developing economies (see Labys and Maizels, 1993; Kinda et al., 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.

⁶¹The 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

2.7. Sectoral structure, price level flexibility and external adjustment

Figure 2.5: 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.

2.7.2 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 2.5, 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?

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 ($\tilde{P}_{H,t}^*$) minus import prices ($\tilde{P}_{F,t}$) as measured at the port:

$$\widehat{ToT}_t = \hat{\tilde{P}}_{H,t}^* - \hat{\tilde{P}}_{F,t},$$

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).

⁶²The 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 2.15 in Appendix 2.C.2). 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 2.17 in Appendix 2.C.1).

2.7. Sectoral structure, price level flexibility and external adjustment

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 ($\tilde{P}_{F,t}$):

$$\begin{aligned}\hat{P}_t &= (1 - \tilde{\gamma})\hat{P}_{N,t} + \tilde{\gamma}\hat{P}_{T,t} \\ &= (1 - \tilde{\gamma})\hat{P}_{N,t} + \tilde{\gamma} \left[\tilde{\alpha}\hat{\tilde{P}}_{H,t} + (1 - \tilde{\alpha})\hat{\tilde{P}}_{F,t} \right],\end{aligned}\tag{2.5}$$

where $\tilde{\gamma}$ denotes the weight of non-tradables in the overall consumption basket, and $\tilde{\alpha}$ denotes the share of home tradables among all tradables. In this way, the *ToT* and CPI can be decomposed into four price components: $\tilde{P}_{H,t}^*$, $\tilde{P}_{F,t}$, $P_{N,t}$ and $\tilde{P}_{H,t}$.

Table 2.6 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 2.B.4).

The export price of H tradable goods ($\tilde{P}_{H,t}^*$) 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 2.5). Despite falling by an equal amount, however, the fall in export prices is likely to increase 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 2.3). 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 2.3). 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 $\tilde{P}_{H,t}^*$ 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 ($\tilde{P}_{H,t}^*$)? 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

2.7. Sectoral structure, price level flexibility and external adjustment

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.

Table 2.6: Local prices, terms of trade and the trade balance

Price	Price change	Substitution effect
$P_{H,t}^*$ (port price of H tradable good)	↓	exports ↑↑
$P_{F,t}$ (port price of F tradable good)	↓	imports ↑
$P_{H,t}$ (local price of H tradable good)	↓↓	imports ↓
Net effects	ToT stable, CPI ↓↓	exports ↑↑

2.7.3 Engel decomposition

Engel (1993) finds that most variation in the real exchange rate today is due to variation in 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):

$$\begin{aligned} \widehat{REER}_t &= \widehat{CPI}_t + \widehat{NEER}_t - \widehat{CPI}_t^* \\ &= \underbrace{\widehat{NEER}_t + \widehat{P}_{T,t} - \widehat{P}_{T,t}^*}_{\equiv q_T} + (1 - \tilde{\gamma}) \underbrace{[(\widehat{P}_{N,t} - \widehat{P}_{T,t}) - (\widehat{P}_{N,t}^* - \widehat{P}_{T,t}^*)]}_{\equiv q_N}, \end{aligned}$$

where we have used (2.5) 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 $\tilde{\gamma}$ denotes the weight of non-tradables in the overall consumption basket. All prices

⁶³Although by the late 19th century important trading centers and coastal cities were internationally well-integrated there was considerable market segmentation further inland (Uebele, 2011).

2.7. Sectoral structure, price level flexibility and external adjustment

are in logs.⁶⁴

Table 2.7 shows how the two components q_T and q_N correlate with the REER. When port prices are used for $P_{T,t}$ and $P_{T,t}^*$ (as suggested by Burstein et al., 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.

Table 2.7: Engel decomposition

	<i>Port prices:</i>			<i>Local prices:</i>			
	Δ REER			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.

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 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

⁶⁴We use local service prices as an indicator for local non-tradable prices $\hat{P}_{N,t}$. The F region's equivalent, $\hat{P}_{N,t}^*$, 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 et al. (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 $\widehat{NEER}_t - \hat{P}_{T,t}^*$. 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, $\hat{P}_{T,t}^*$, is a trade-weighted average of the corresponding prices in all other countries.

⁶⁵This finding is also consistent with the finding by Burstein et al. (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.

2.8. Conclusion

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 et al. (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.

2.8 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

2.8. Conclusion

Standard after World War 1 and its fall in the 1930s, which is often attributed to the rise of rigid wages (see Bordo et al., 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.

2.A Data appendix

2.A.1 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 et al. (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 et al. (2009) and Global prices and incomes database (raw materials). Terms of trade: Horlings (2002).

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)

2.A. Data appendix

(1900-1908). Immigration & emigration: Urquhart and Buckley (1965) & Viner (1924). Population: The Maddison-Project (2013). Narrow and broad cover ratio: Leacy et al. (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: The 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: The 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 et al. (2009). Terms of trade: Hjerppe (1989). Export prices: Hjerppe (1989).

France: Nominal GDP: Mitchell (2013). Real per capita GDP: Barro and Ursúa (2010).

2.A. Data appendix

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: The Maddison-Project (2013). Central bank discount rate: 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 et al. (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 et al. (2000). Real per capita GDP: Barro and Ursúa (2010). CPI: Taylor (2002). Current account: Smits et al. (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: Jong (1967) (1870-1875), Vergleichende Notenbankstatistik: Organisation

2.A. Data appendix

und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925) (1876-1879) and Flandreau and Zumer (2004) (1880-1913). Narrow cover ratio: Jong (1967) (1870-1875) and Vergleichende Notenbankstatistik: Organisation und Geschäftsverkehr wichtiger europäischer Notenbanken, 1876-1913 (1925) (1876-1913). Broad cover ratio: Jong (1967). Notes in circulation: 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: The 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: The 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

2.A. Data appendix

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: The Maddison-Project (2013). Central bank discount rate: Edvinsson et al. (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 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 et al. (2015). Real per capita GDP: Barro and Ursúa (2010). CPI: Hills et al. (2015). Current account: Jones and Obstfeld (2004) (adjusted for monetary gold flows). Exports & imports: Hills et al. (2015). Nominal USD-exchange rate: Officer (2015). Immigration & emigration: Mitchell (2013). Population: The Maddison-Project (2013). Central bank discount rate: Hills et al. (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

2.A. Data appendix

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 et al. (2015). Export prices: Hills et al. (2015).

United States: Nominal GDP: Johnston and Williamson (2011). Real per capita GDP: Barro and Ursúa (2010). CPI: Hills et al. (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: The 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 Department of Commerce and Labor Bureau 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).

2.A.2 Migration data

One important source for migration numbers are port statistics, which have been introduced in most early developing countries after the Napoleonic wars.⁶⁶ 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

⁶⁶The following description of the migration data makes ample use of the data descriptions given in Ferenczi (1929) and Mitchell (2013).

2.A. Data appendix

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 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 2.A.4 lists information about the degree of return migration where such information is available.

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.⁶⁷

⁶⁷Only if reporting periods were straddled by important holiday or business-traveling seasons would the

2.A. Data appendix

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:

$$netim_t = pop_t - pop_{t-1} * (1 + BR_t - DR_t).$$

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.⁶⁸ 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.⁶⁹ 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 2.6 plots the two net immigration/population series – one derived from the migration statistics (plus symbols), and the other derived from the census population enumerations and vital statistics (circle symbols).⁷⁰ 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

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.

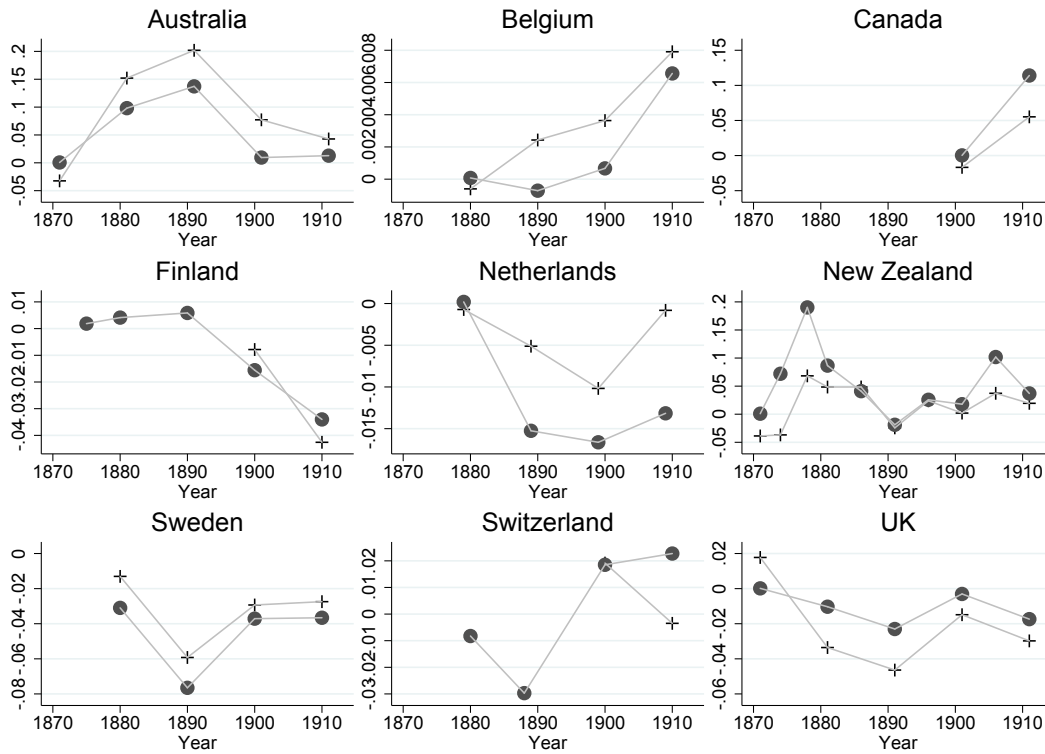
⁶⁸The same argument is provided by primary sources when explaining the discrepancy between population estimates and population enumerations. See, for example, the population statistics section of the Official yearbook of the Commonwealth of Australia from 1913.

⁶⁹For the same reason we do not calculate a vital statistics-based net immigration series for France, because the French immigration series we use was itself 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).

⁷⁰For 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.

2.A. Data appendix

Figure 2.6: 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 preceding census' population data, death rates and birth rates.

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.⁷¹

2.A.3 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

⁷¹Note that for the model estimation we allow for measurement error in the net immigration series.

2.A. Data appendix

produced goods.

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 2.7. 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.

2.A.4 Sectoral exports

How much of international trade does our 14 country gold block sample cover? To answer this question we calculated within Gold Standard trade shares:

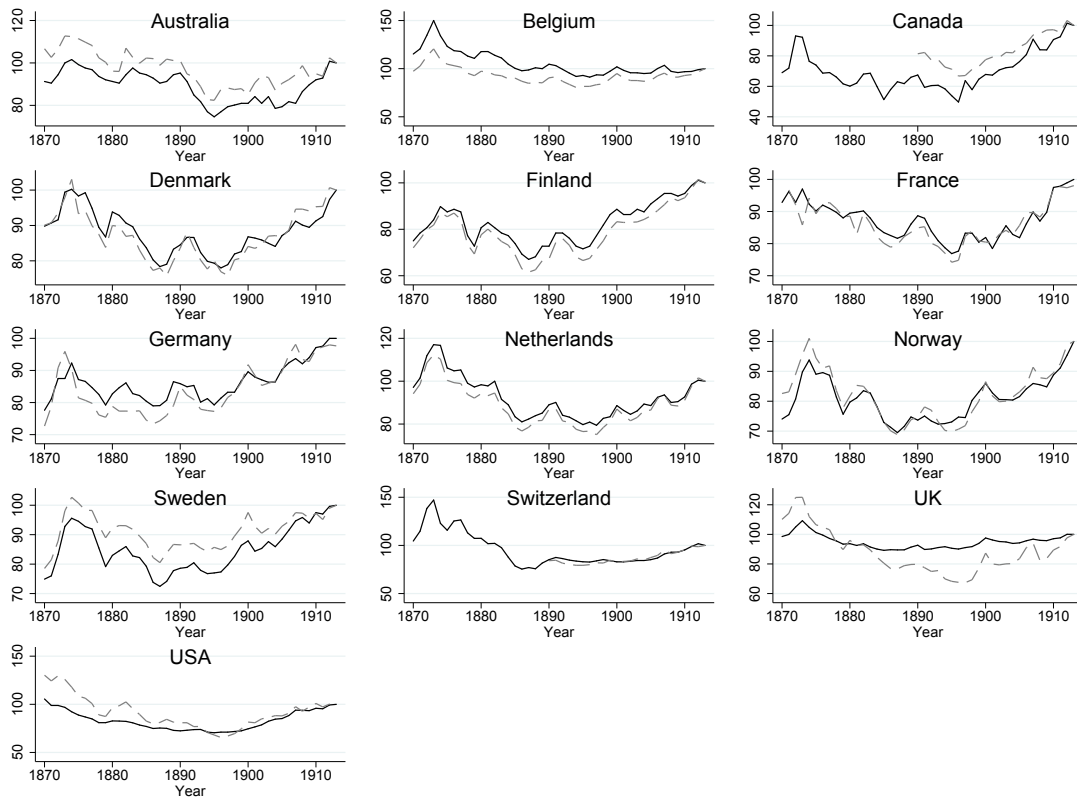
$$impshare_{i,t} = \frac{\sum_{j \in gold} imp_{ij,t}}{imp_{i,t}} \quad \text{and} \quad expshare_{i,t} = \frac{\sum_{j \in gold} exp_{ij,t}}{exp_{i,t}},$$

where i is the country index and t the time index.⁷²

⁷²We use bilateral trade flow data provided by Barbieri et al. (2008), Jacks et al. (2011) and Mitchell (2013).

2.A. Data appendix

Figure 2.7: 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)).

The average import and export shares are listed in Table 2.8. 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 than one quarter of trade for the gold block countries.⁷³

⁷³Note 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,

2.A. Data appendix

Table 2.8: 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.

France, the U.K. and the U.S. among the gold block countries.

Table 2.9: Sectoral price data

Country	Time	Source	Notes
Australia	1870-1913	Butlin (1962)	<i>agricultural</i> : average of pastoral, agriculture and dairying price indexes. 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. <i>raw materials</i> : 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). <i>industrial</i> : industrial price index (composed of four industrial goods' wholesale price series, and industrial wage-rates). <i>services</i> : based on prices for private water transport, government business undertakings (railway freight rates and wage incomes), government services, property and finance, professional and domestic service, distribution.
Belgium	1870-1913	<i>agricultural, industrial & services</i> : Smits et al. (2009). <i>raw materials</i> : Global prices and incomes database.	<i>agricultural</i> : implicit agricultural, hunting and forestry deflator. <i>raw materials</i> : average price of lampoil, kerosene and coal in Ghent 1816-1925. <i>industrial</i> : industry deflator. <i>services</i> : 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	<i>agricultural</i> : 1870-1913. <i>raw material & industrial</i> : 1890-1913. <i>services</i> : 1900-1913.	Urquhart and Buckley (1965)	<i>agricultural</i> : wholesale prices of 15 foodstuffs (from Toronto newspapers). <i>raw materials</i> : wholesale price of raw and partly manufactured goods. <i>industrial</i> : wholesale price of fully and chiefly manufactured goods. <i>services</i> : index based on prices for domestic electric light and hospital charges.
Denmark	1870-1913	Hansen (1974)	<i>agricultural</i> : implicit deflator for agricultural production. <i>raw material</i> : implicit deflator for forestry, peat- and lignite production. <i>industrial</i> : implicit deflator for craftsmanship, industry, etc. <i>services</i> : implicit deflator of trade etc.
Finland	1870-1913	Smits et al. (2009)	<i>agricultural</i> : implicit deflator for agricultural and fishing production. <i>raw materials</i> : implicit deflators for forestry production. <i>industrial</i> : implicit deflator for manufacturing production. <i>services</i> : implicit deflator for trade, transport, storage and communications, financial intermediation, real estate, renting and business activities.

France	<i>agricultural & raw material:</i> 1871-1913. <i>industrial & services:</i> 1870-1913.	<i>agricultural & raw material:</i> Brandau (1936). <i>industrial & services:</i> Smits et al. (2009).	<i>agricultural & raw material:</i> wholesale price indices. <i>industrial:</i> implicit deflator for total industry production. <i>services:</i> 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	<i>agricultural, industrial & services:</i> Hoffmann (1965). <i>raw materials:</i> Müssig (1919).	<i>agricultural:</i> retail- and wholesale prices. <i>raw materials:</i> price index based on prices for coal, coke, spar, ore, iron. <i>industrial:</i> 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. <i>services:</i> price index based on services of doctors and nursing staff, housing, domestic services, education, recreation, transport and public consumption.
Netherlands	1870-1913	<i>agricultural, industrial & services:</i> Van Zanden, J.L., National Accounts of the Netherlands, 1800-1913. <i>raw materials:</i> Van Riel (2000).	<i>agricultural, industrial & services:</i> sectoral deflators. <i>raw materials:</i> based on prices for copper, tin, lead, coal and peat.
New Zealand	<i>agricultural:</i> 1870-1913. <i>raw materials:</i> 1870-1910.	<i>agricultural:</i> Arnold (1982). <i>raw materials:</i> McLraith (1911).	<i>agricultural:</i> total food consumer prices. <i>raw materials:</i> non-farm commodity price index.
Norway	1870-1913	<i>agricultural, raw materials & industrial:</i> Klovland (2005). <i>services:</i> Grytten (2015).	<i>agricultural:</i> based on prices for feeding stuffs, vegetables, grain, fish, dairy product and meat. <i>raw materials:</i> based on prices for metals, minerals and timber and wood. <i>industrial:</i> based on prices for manufactures of wood and manufactures of textiles. <i>services:</i> 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.	<i>agricultural</i> : based on prices of products from agriculture, forestry, hunting and fishing, horticulture sectors. <i>raw materials</i> : based on prices of products from mining and metals industry. <i>industrial</i> : based on prices of products from paper and printing industries, textile and clothing industry, leather, hair and rubber industries, chemical industries, building and construction. <i>services</i> : 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	<i>agricultural, raw materials & industrial</i> :1870-1913. <i>services</i> : 1890-1913.	Historical Statistics of Switzerland Online	<i>agricultural</i> : price index for food and beverage: animal, vegetable and processed products. <i>raw materials</i> : price index for fuels, chemicals, metals and building materials. <i>industrial</i> : price index for textiles (cotton, silk, wool, linen), skins and leather. <i>services</i> : tertiary sector, implicit deflator.
United Kingdom	<i>agricultural, raw materials & industrial</i> : 1870-1913	<i>agricultural</i> : Clark (2004). <i>raw materials</i> : Layton and Crowther (1935). <i>industrial</i> : Maynard (1962) Tinbergen (1956)	<i>agricultural</i> : 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. <i>raw materials</i> : raw material price index based on the wholesale price of 44 to 45 commodities. <i>industrial</i> : based on prices for clothing, durable household goods and other goods. <i>service</i> : based on prices for transport and communication, and other services.
USA	<i>agricultural, raw materials & industrial</i> : 1870-1913	<i>agricultural & industrial</i> : Historical Statistics of the United States 1789-1945. <i>raw materials</i> : Brandau (1936).	<i>agricultural</i> : wholesale farm product price index. <i>raw materials</i> : wholesale prices for industrial raw materials. <i>industrial</i> : wholesale prices of textile products, chemicals and drugs, house-furnishing goods. <i>service</i> : imputed with sectoral share data and GDP deflator.

Table 2.10: 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)	Little 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.

Table 2.11: Export categories

Country	Disaggregate export component series:		
	Agricultural	Raw material	Industrial
Australia	<p><i>1880-1898</i>: wool, tallow, butter, live stock, meat, sugar, wheat and flour, jams, fruit, potatoes and other vegetable products.</p> <p><i>1899-1900</i>: 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).</p> <p><i>1901-1912</i>: animal foodstuffs etc., vegetable foodstuffs etc., beverages (non-alcoholic), alcoholic liquors, tobacco, live animals, animal substances, vegetable substances.</p>	<p><i>1880-1898</i>: coal, silver (lead and ore), tin, copper, hides and skins, gold, minerals, timber, sandal-wood, pearl shell, pearls, guano.</p> <p><i>1899-1900</i>: 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 bullion.</p> <p><i>1901-1912</i>: oils, stones, metals (ores), wood.</p>	<p><i>1880-1912</i>: apparel, paints, metals (part manufactured and manufactured), leather, earthenware, paper, jewellery, instruments, drugs</p>

Belgium	<i>1870-1913</i> : 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	<i>1870-1913</i> : 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	<i>1870-1913</i> : 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	<i>1870-1913</i> : products of fisheries, animals and products of, agricultural product	<i>1870-1913</i> : products of mines, products of forest (raw)	<i>1870-1913</i> : products of the forest (manufactured and partially manufactured), manufactures
Denmark	<i>1870-1873</i> : meat and cattle, pork and pigs, butter, other animal, cereals, flour, grains and bread, other vegetable, food, drink. <i>1874-1883</i> : agricultural exports.	<i>1870-1873</i> : hides and skins. <i>1884-1912</i> : coal, coffee (raw), coffee (roasted), oil/petroleum and other, sugar (raw and refined), tobacco, wood.	<i>1870-1873</i> : goods of iron and metal industry, textile and clothing, articles of stone/clay and glass industry, other industrial goods.

	<p><i>1884-1912</i>: 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).</p> <p><i>1913</i>: living animals, animal products, cereals, fodder, garden products and fruit, beverages and spirits, diverse plant materials.</p>	<p><i>1913</i>: colonial goods, skins/fur/feathers/boise (and other animal products), tallow/oil/rubber/resin/tar, wood, minerals (raw or drafted), other metals</p>	<p><i>1884-1912</i>: hides and skins (prepared and manufactured), iron and steel manufactures, wool manufactures.</p> <p><i>1913</i>: 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.</p>
Finland	<p><i>1875-1880</i>: agricultural exports.</p> <p><i>1882-1891</i>: 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.</p> <p><i>1892-1913</i>: 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.</p>	<p><i>1875-1880</i>: forestry, wood industry.</p> <p><i>1882-1891</i>: 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.</p> <p><i>1892-1913</i>: colonial goods, skin and leather, pelts, wood (raw and products), resin and tar, oils and fats, minerals (raw and processed), metals.</p>	<p><i>1875-1880</i>: paper, textile industry, metal and engineering industries, other manufacturing.</p> <p><i>1882-1891</i>: 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.</p> <p><i>1892-1913</i>: 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.</p>

France	<i>1870-1913</i> : 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).	<i>1870-1913</i> : hides (raw), iron/steel and manufactures of), pig iron, steel ingots/billets etc., oils (volatile and essential), rags (wollen), silk (raw, throw, waste and cocoons), sugar (raw and refined), wood (common).	<i>1870-1913</i> : 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	<i>1872-1913</i> : food industry exports	<i>1872-1913</i> : raw materials and semifinished products, metals	<i>1872-1913</i> : finished products
Netherlands	<i>1878-1889</i> : 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. <i>1878-1889</i> : articles of food and live animals.	<i>1878-1889</i> : 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, salpêtre (unrefined), spelter or zinc (unwrought), sugar, tin (unwrought), tobacco (leaf). <i>1878-1889</i> : raw materials.	<i>1878-1889</i> : candles, cotton (yarn and manufactures), drugs (Peruvian bark and other), dye stuffs, iron bars (rails etc.), iron wares (incl. nails and wire), steel and manufactures, machinery of all kinds, wool (yarn and manufactures). <i>1878-1889</i> : manufactured articles

New Zealand	<p><i>1870-1874</i>: wool, meat, butter, dairy, grain. <i>1875-1880</i>: 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), <i>1881-1913</i>: the fisheries, animals and produce, agricultural products.</p>	<p><i>1870-1874</i>: timber, gum, gold <i>1875-1880</i>: gold, silver, coal, kauri gum, timber (sawn and hewn, logs, spars, laths, palings, posts and shii). <i>1881-1913</i>: the mine, the forest.</p>	<p><i>1875-1880</i>: leather, cordage, phormium (New Zealand hemp), <i>1881-1913</i>: manufactures.</p>
Norway	<p><i>1878-1900</i>: horses, beer, fish (fresh), cod (dried or split), herrings (salted), other salted fish, anchovies, lobster, fish roes, grain (oats), <i>1901-1913</i>: bran, butter, condensed milk, fish (fresh), cod (dried or split), herrings (salted), other salted fish, anchovies, lobster, fish roes</p>	<p><i>1878-1900</i>: 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). <i>1901-1913</i>: 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).</p>	<p><i>1878-1900</i>: iron manufactures (nails), lucifer matches, cotton manufactures, packing paper, wood manufactures, wood pulp (mechanical process), wood pulp (chemical process). <i>1901-1913</i>: calcium carbide, iron nails, lucifer matches, paper (packing), paper (printing), sailing and steam vessels, wood pulp (mechanical and chemical process)</p>
Sweden	<p><i>1870-1913</i>: agriculture and subsidiaries, food industries.</p>	<p><i>1870-1913</i>: mining metal, stone and clay, wood industries, leather and rubber</p>	<p><i>1870-1913</i>: paper industries, textile and clothing, chemical industries</p>
Switzerland	<p><i>1885-1913</i>: articles of food</p>	<p><i>1885-1913</i>: raw materials</p>	<p><i>1885-1913</i>: manufactured articles</p>

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), soles and slates (slate by tale), wool (sheep and lambs, nolls, waste).
1898-1913: coal, coke and patent fuel, iron ore, other metallic ores, wood and timber, cotton, wool (sheep and lambs; woll waste, noils) other textile materials, oil seeds nuts, oils, fats and gum

, hides and undressed skins, materials for paper making, miscellaneous raw materials and articles mainly unmanufactured.

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 millinery

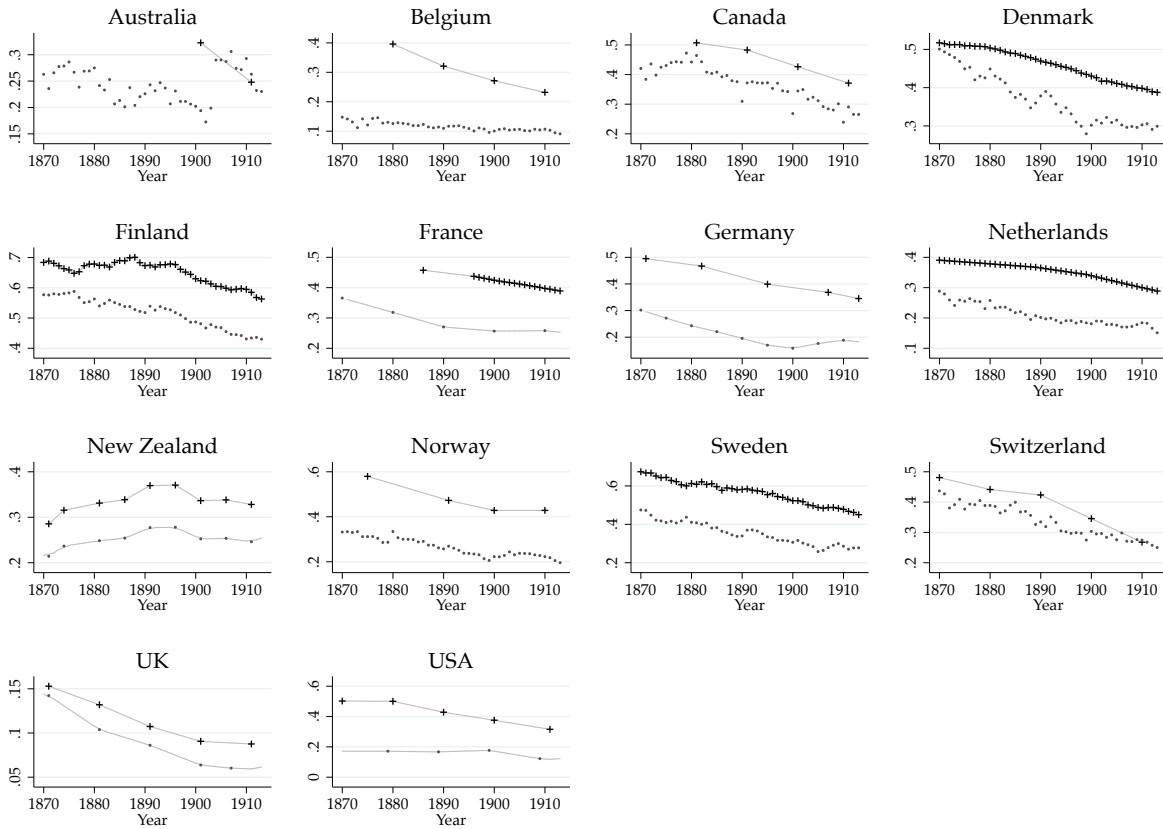
, hardware and cutlery, hats, implements of tools of industry, instruments and apparatus, leather, linen yarn, jute yarn, linen manufactures, jute manufactures, steam engines, other machines, medicines, metals, musical instruments, oil and floor cloth, painters' colors, paper and pasteboard, pictures, 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 apparaturs, 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 manufactured

USA	<i>1870-1912</i> : foodstuffs in crude condition and food animals, foodstuffs partly or wholly prepared.	<i>1870-1912</i> : crude materials for use in manufactures.	<i>1870-1912</i> : manufactures for further use in manufactures, manufactures ready for consumption.
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2.A. Data appendix

2.A.5 Primary sector shares

Figure 2.8: Primary sector shares

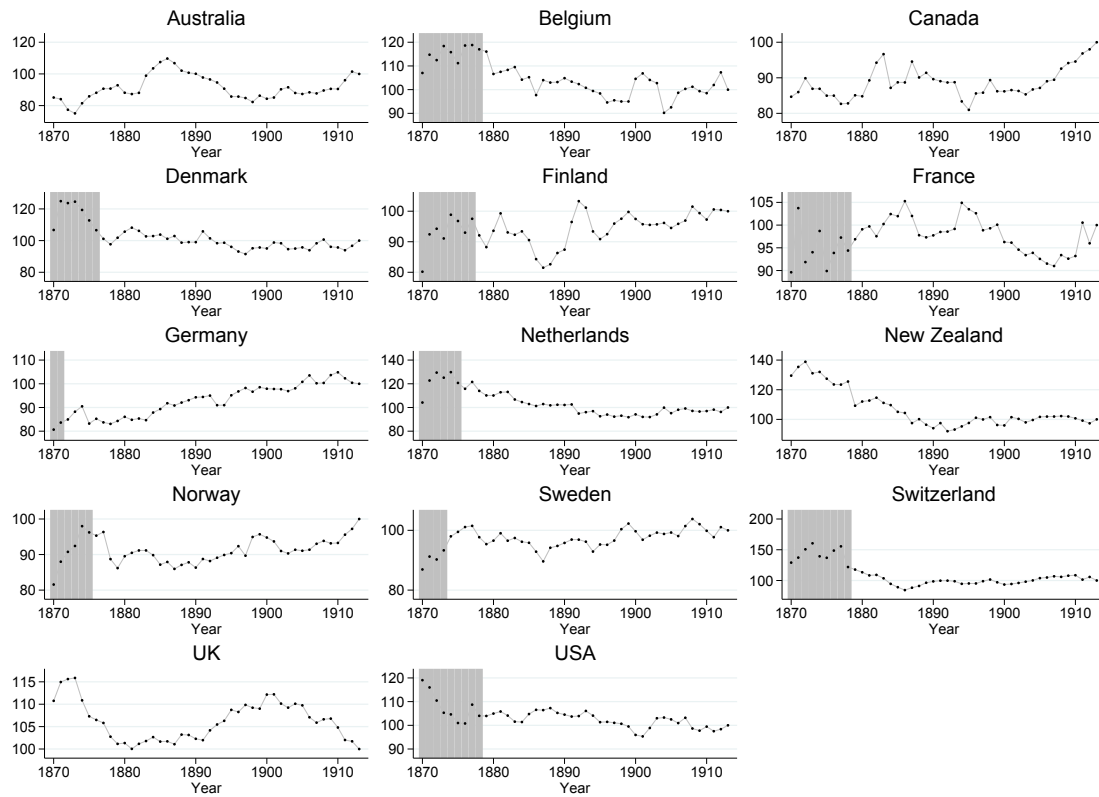


Notes: Plus sign – primary sector employment share (i.e. agriculture and raw materials). Circles – agricultural sector value added share. Plus signs and circles indicate observations. Grey lines are linearly inter- and extrapolated values.

2.A. Data appendix

2.A.6 Real effective exchange rates

Figure 2.9: REERs within the Gold Standard

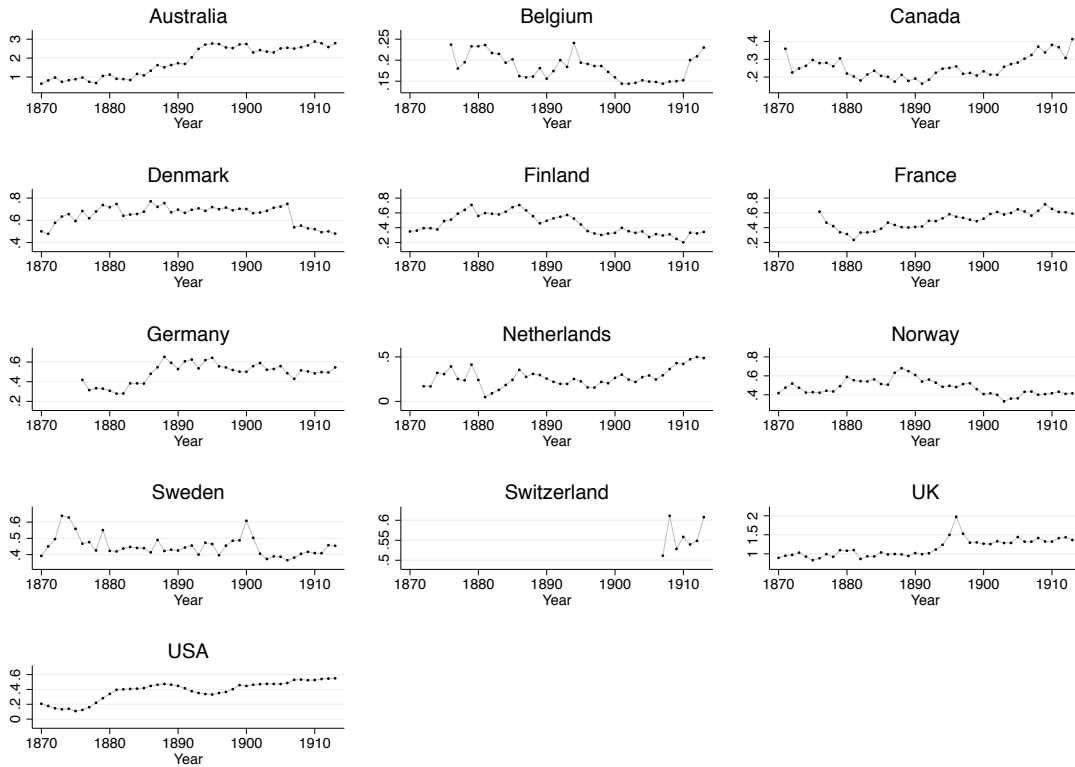


Notes: Grey – not on Gold Standard.

2.A. Data appendix

2.A.7 Gold cover ratios

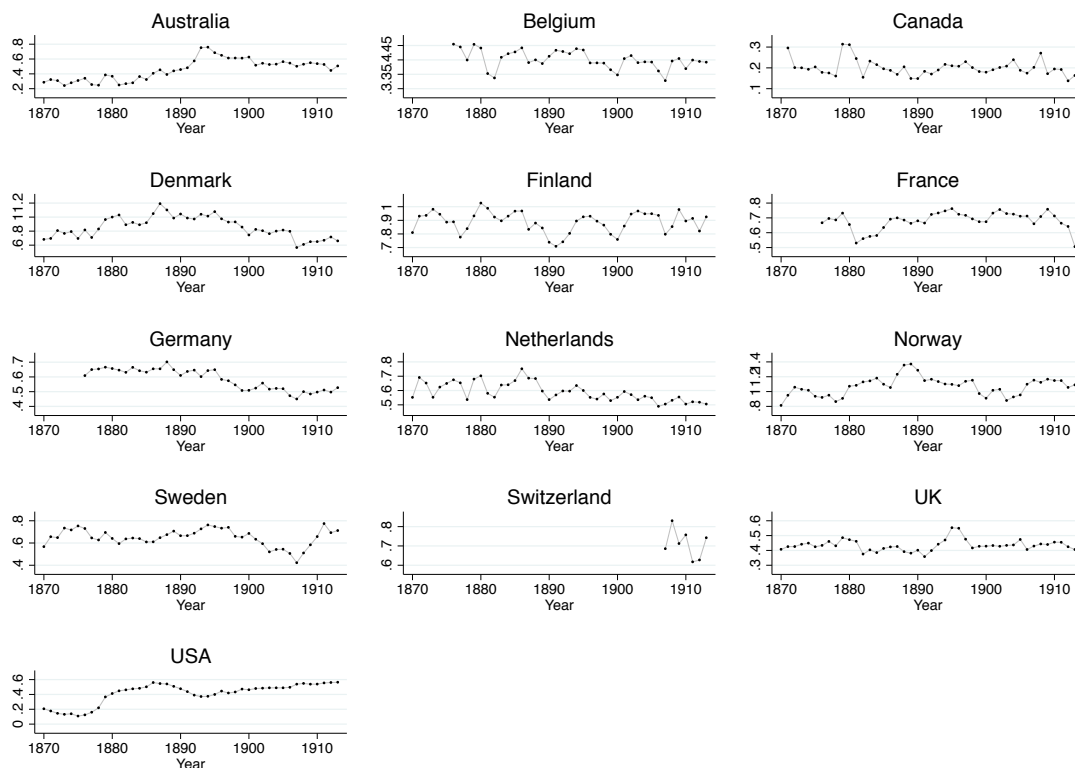
Figure 2.10: Gold cover ratios, narrow



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 guaranteeing 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.

2.A. Data appendix

Figure 2.11: Gold cover ratios, broad

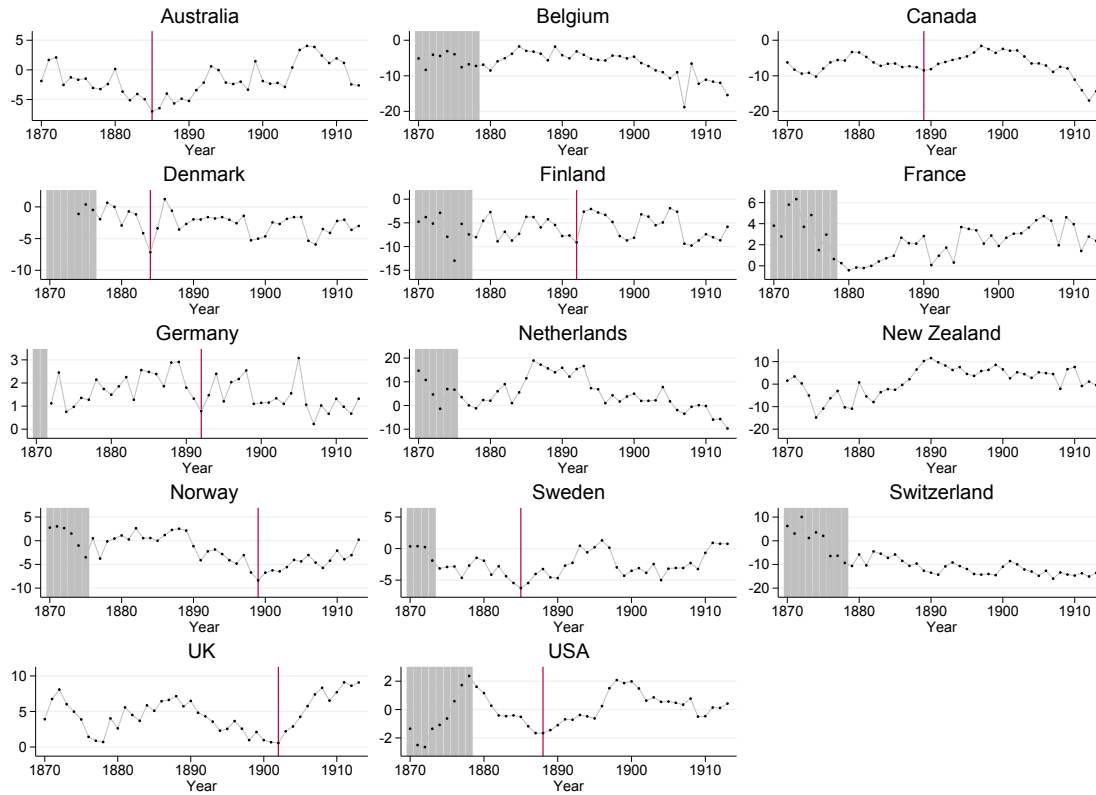


Notes: The figure depicts broadly defined gold cover ratios: $\text{Gold cover ratio} = (\text{Metal reserves} + \text{foreign exchange reserves}) / (\text{central bank notes in circulation} + \text{central bank deposits})$. In the absence of a central bank (e.g. Australia, Canada and the U.S.) the gold cover ratio has been calculated as the ratio of gold-, specie and foreign exchange reserves in the institution guaranteeing 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.

2.A. Data appendix

2.A.8 Adjustment periods

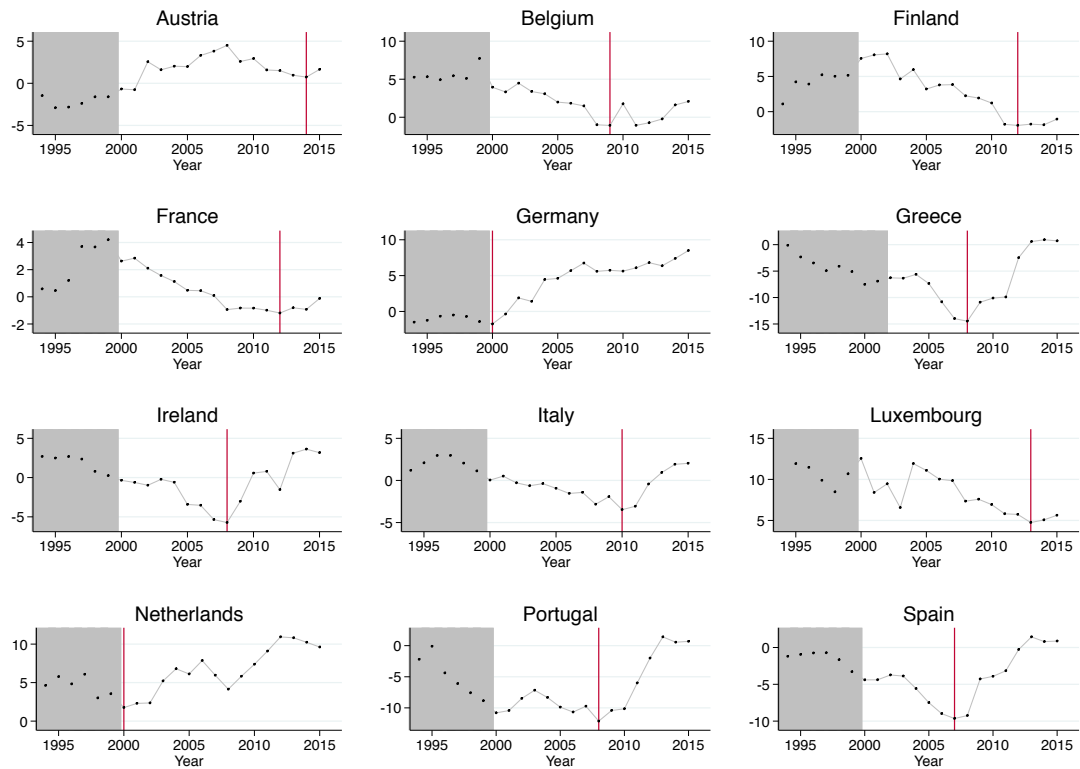
Figure 2.12: CA/GDP within the Gold Standard



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.

2.A. Data appendix

Figure 2.13: 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.

2.B Model appendix

2.B.1 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:

$$\begin{aligned} \Upsilon_t^i &= \max_{\{\text{stay, migrate}\}} \{V_t^i, V_t^{i*} + v_t^i - \kappa_d\}, \text{ with } v_t^i \stackrel{iid}{\sim} \text{Logistic} \left(0, \frac{(\pi\psi)^2}{3} \right) \\ d_t^i &= \text{Prob} (V_t^i \leq V_t^{i*} + v_t^i - \kappa_d) \\ \Rightarrow \Upsilon_t^i &= \psi \ln \left(\exp \left(\frac{V_t^i}{\psi} \right) + \exp \left(\frac{V_t^{i*} - \kappa_d}{\psi} \right) \right), \quad d_t^i = \left[1 + \exp \left(\frac{V_t^i - V_t^{i*} + \kappa_d}{\psi} \right) \right]^{-1} \end{aligned}$$

The second stage decision is

$$\begin{aligned} V_t^i &= \max_{c_t^i, l_t^i, B_{H,t}^i, B_{F,t}^i} \frac{1}{1 - \sigma_c} \left(c_t^i - \frac{1}{1 + \sigma_l} l_t^{i1+\sigma_l} \right)^{1-\sigma_c} + \beta \mathbb{E}_t \Upsilon_{t+1}^i, \\ \text{s.t. } & B_{H,t-1}^i R_{t-1}^e + B_{F,t-1}^i R_{t-1}^{e*} / e_t + T R_t + P_t w_t l_t^i + \Gamma_t + I_t^T \\ &= B_{H,t}^i + B_{F,t}^i / e_t + P_t c_t^i + P_t \frac{K}{2} \left(\frac{B_{F,t}^i}{P_t e_t} - \bar{o} \right)^2 \end{aligned}$$

The budget constraint for a F household is:

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

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

2.B. Model appendix

$E_{r,t} = P_t e_t / P_t^*$ the first order conditions imply

$$\lambda_t = \left(c_t - \frac{l_t^{1+\sigma_l}}{1+\sigma_l} \right)^{-\sigma_c} \quad (2.B.1)$$

$$\lambda_t^* = \left(c_t^* - \frac{(l_t^*)^{1+\sigma_l}}{1+\sigma_l} \right)^{-\sigma_c} \quad (2.B.2)$$

$$\lambda_t = \beta R_t^e \mathbb{E}_t \left(\frac{(1-d_{t+1}) \lambda_{t+1}}{\Pi_{t+1}} + \frac{d_{t+1} \lambda_{t+1}^* E_{r,t+1}}{\Pi_{t+1}} \right) \quad (2.B.3)$$

$$\lambda_t^* = \beta R_t^{e*} \mathbb{E}_t \left(\frac{(1-d_{t+1}^*) \lambda_{t+1}^*}{\Pi_{t+1}^*} + \frac{d_{t+1}^* \lambda_{t+1}}{\Pi_{t+1}^* E_{r,t+1}} \right) \quad (2.B.4)$$

$$\lambda_t = \beta R_t^{e*} \frac{1}{1 + \mathbb{K} (b_{F,t} / E_{r,t} - \bar{\delta})} \frac{e_t}{e_{t+1}} \mathbb{E}_t \left(\frac{(1-d_{t+1}) \lambda_{t+1}}{\Pi_{t+1}} + \frac{d_{t+1} \lambda_{t+1}^* E_{r,t+1}}{\Pi_{t+1}} \right) \quad (2.B.5)$$

$$\lambda_t^* = \beta R_t^e \frac{1}{1 + \mathbb{K} (b_{H,t}^* E_{r,t} - \bar{\delta}^*)} \frac{e_{t+1}}{e_t} \mathbb{E}_t \left(\frac{(1-d_{t+1}^*) \lambda_{t+1}^*}{\Pi_{t+1}^*} + \frac{d_{t+1}^* \lambda_{t+1}}{\Pi_{t+1}^* E_{r,t+1}} \right) \quad (2.B.6)$$

$$l_t^{\sigma_l} = w_t \quad (2.B.7)$$

$$l_t^{*\sigma_l} = w_t^* \quad (2.B.8)$$

The population evolves according to

$$n_t = n_{t-1} (1 - d_t) + d_t^* n_{t-1}^* \quad (2.B.9)$$

$$n_t^* = 1 - n_t \quad (2.B.10)$$

2.B. Model appendix

Firm j 's optimization problem is

$$\max_{P_{H,t}(j)} \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ (\beta\theta)^k \frac{\lambda_{t+k}}{\lambda_t} \frac{P_t}{P_{t+k}} \left[P_{H,t}(j) y_t(j) - w_{t+k} P_{t+k} l_{t+k}(j) \right] \right\} \quad (2.B.11)$$

$$\text{s.t. } y_{t+k}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t+k}} \right)^{-\mu} y_{t+k} \quad (2.B.12)$$

$$y_{t+k}(j) = A_{t+k} l_{t+k}^\gamma \quad (2.B.13)$$

The first order condition leads to

$$\begin{aligned} F_t &= \lambda_t y_t \left(\frac{P_{H,t}}{P_t} \right) \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{1-\mu} \\ &\quad + \beta \theta \mathbb{E}_t \left(\frac{\left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right) \frac{1}{\Pi_{H,t+1}}}{\left(\frac{P_{H,t+1}^{opt}}{P_{H,t+1}} \right)} \right)^{1-\mu} F_{t+1} \end{aligned} \quad (2.B.14)$$

$$\begin{aligned} K_t &= w_t \frac{\lambda_t}{\gamma} \frac{\mu}{\mu-1} \left(\frac{y_t}{A_t} \right)^{\frac{1}{\gamma}} \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{\frac{-\mu}{\gamma}} \\ &\quad + \beta \theta \mathbb{E}_t \left(\frac{\left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right) \frac{1}{\Pi_{H,t+1}}}{\left(\frac{P_{H,t+1}^{opt}}{P_{H,t+1}} \right)} \right)^{\frac{-\mu}{\gamma}} K_{t+1} \end{aligned} \quad (2.B.15)$$

$$K_t = F_t \quad (2.B.16)$$

The price dynamics are described by

$$1 - \theta \left(\frac{1}{\Pi_{H,t}} \right)^{1-\mu} = (1 - \theta) \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{1-\mu} \quad (2.B.17)$$

$$\Delta_t^P = \theta \Delta_{t-1}^P \Pi_{H,t}^{\frac{\mu}{\gamma}} + (1 - \theta) \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{\frac{(-\mu)}{\gamma}} \quad (2.B.18)$$

2.B. Model appendix

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

$$R_t = \bar{R}^{1-\rho} R_{t-1}^\rho \left(\frac{y_t}{\bar{y}} \right)^{(1-\rho)\Phi_y} \left(\frac{\gamma_t}{\bar{\gamma}} \right)^{(1-\rho)\Phi_g} \left(\frac{e_t}{\bar{e}} \right)^{-(1-\rho)\Phi_e} \quad (2.B.19)$$

$$P_{H,t} n y_t = \exp(\chi_t) M_t k(R_t) \quad (2.B.20)$$

$$G_t = G_{t-1} + F(e_t) \exp(\epsilon_{m,t}) \quad (2.B.21)$$

$$\gamma_t M_t = P_g G_t, \quad (2.B.22)$$

The market clearing conditions are

$$y_t n = (1 - \alpha) \left(\frac{P_{H,t}}{P_t} \right)^{-\epsilon} c_t n_t + \alpha^* \left(\frac{P_{H,t}^*}{P_t^*} \right)^{-\epsilon^*} c_t^* n_t^* \quad (2.B.23)$$

$$\Delta_t^P n y_t^{\frac{1}{\gamma}} = l_t n_t A_t^{\frac{1}{\gamma}} \quad (2.B.24)$$

$$0 = n_t B_{H,t} + n_t^* B_{H,t}^* \quad (2.B.25)$$

$$0 = n_t B_{F,t} + n_t^* B_{F,t}^* \quad (2.B.26)$$

Auxiliary variables:

$$ToT_t = \frac{P_{H,t}^*}{P_{F,t}} \quad (2.B.27)$$

$$\Pi_t = \frac{P_t}{P_{t-1}} \quad (2.B.28)$$

$$\Pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}} \quad (2.B.29)$$

$$TB_t = n_t^* c_{H,t}^* P_{H,t} - n_t c_{F,t} P_{F,t} \quad (2.B.30)$$

$$c_{H,t} = (1 - \alpha) \left(\frac{P_{H,t}}{P_t} \right)^{-\epsilon} c_t \quad (2.B.31)$$

$$c_{H,t}^* = \alpha^* \left(\frac{P_{H,t}^*}{P_t^*} \right)^{-\epsilon^*} c_t^* \quad (2.B.32)$$

$$c_{F,t} = \alpha \left(\frac{P_{F,t}}{P_t} \right)^{-\epsilon} c_t \quad (2.B.33)$$

2.B. Model appendix

$$c_{F,t}^* = (1 - \alpha^*) \left(\frac{P_{F,t}^*}{P_t^*} \right)^{-\epsilon^*} c_t^* \quad (2.B.34)$$

2.B.2 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 (2.B.4) and (2.B.6) it follows that $\bar{R} = \bar{R}^*$. Using (2.B.4) and (2.B.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

$$\bar{\lambda} / \bar{E}_r = \bar{\lambda}^* \quad (2.B.35)$$

$$\bar{\lambda} = \left(\bar{c} - \frac{\bar{l}^{1+\sigma_l}}{1 + \sigma_l} \right)^{-\sigma_c} \quad (2.B.36)$$

$$\bar{\lambda}^* = \left(\bar{c}^* - \frac{(\bar{l}^*)^{1+\sigma_l}}{1 + \sigma_l} \right)^{-\sigma_c} \quad (2.B.37)$$

From (2.B.14), (2.B.16), and (2.B.16) and the corresponding equations for F , we obtain

$$\bar{w} = \gamma \bar{y} \frac{\bar{P}_H}{\bar{P}} \left(\frac{\bar{y}}{\bar{A}} \right)^{-1/\gamma} \frac{\mu - 1}{\mu} \quad (2.B.38)$$

$$\bar{w}^* = \gamma \bar{y}^* \frac{\bar{P}_F^*}{\bar{P}^*} \left(\frac{\bar{y}^*}{\bar{A}^*} \right)^{-1/\gamma} \frac{\mu - 1}{\mu} \quad (2.B.39)$$

The steady state labor supply satisfies

$$\bar{l}_l^\sigma = \bar{w} \quad (2.B.40)$$

$$(\bar{l}^*)^{\sigma_l} = \bar{w}^* \quad (2.B.41)$$

At the steady state, the asset pooling assumption gives us

$$\begin{aligned} \bar{n} \bar{b} &= n(1 - \bar{d})(\bar{b}_H \bar{R} + \bar{b}_F \bar{R} / \bar{E}_r) + \bar{d}^* (1 - \bar{n})(\bar{b}_H^* \bar{R} + \bar{b}_F^* \bar{R} / \bar{E}_r) \\ (1 - \bar{n}) \bar{b}^* &= (1 - \bar{n})(1 - \bar{d}^*)(\bar{b}_F^* \bar{R} + \bar{b}_H^* \bar{R} \bar{E}_r) + \bar{d} \bar{n} (\bar{b}_F \bar{R} + \bar{b}_H \bar{R} \bar{E}_r) \end{aligned}$$

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

$$\begin{aligned} \bar{n} \bar{b} &= \bar{R}(1 - \bar{d} - \bar{d}^*) \bar{\Omega} \bar{n} \\ (1 - \bar{n}) \bar{b}^* / \bar{E}_r &= -\bar{R}(1 - \bar{d} - \bar{d}^*) \bar{\Omega} \bar{n} \end{aligned}$$

2.B. Model appendix

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

$$\bar{n} \frac{\bar{P}_H}{\bar{P}} \bar{y} + (1 - \bar{n}) \frac{\bar{P}_F^*}{\bar{P}^*} \bar{y}^* / \bar{E}_r = \bar{n} \bar{c} + (1 - \bar{n}) \bar{c}^* / \bar{E}_r \quad (2.B.42)$$

which reflects the resources constraint of the whole economy in terms of H currency. The goods and labor market clearing conditions imply

$$\bar{y} \bar{n} = (1 - \alpha) \left(\frac{\bar{P}_H}{\bar{P}} \right)^{-\epsilon} \bar{c} \bar{n} + \alpha^* \left(\frac{\bar{P}_H \bar{E}_r}{\bar{P}} \right)^{-\epsilon^*} \bar{c}^* (1 - \bar{n}) \quad (2.B.43)$$

$$\bar{y}^* (1 - \bar{n}) = \alpha \left(\frac{\bar{P}_F^*}{\bar{P}^* \bar{E}_r} \right)^{-\epsilon^*} \bar{c} \bar{n} + (1 - \alpha^*) \left(\frac{\bar{P}_F^*}{\bar{P}^*} \right)^{-\epsilon^*} (1 - \bar{n}) \bar{c}^* \quad (2.B.44)$$

$$\bar{y} = \bar{A} \bar{l}^\gamma \quad (2.B.45)$$

$$\bar{y}^* = \bar{A}^* (\bar{l}^*)^\gamma \quad (2.B.46)$$

Prices in the steady state satisfy

$$1 = (1 - \alpha) \left(\frac{\bar{P}_H}{\bar{P}} \right)^{1-\epsilon} + \alpha \left(\frac{\bar{P}_F^*}{\bar{P}^* \bar{E}_r} \right)^{1-\epsilon} \quad (2.B.47)$$

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 (2.B.35) - (2.B.47).

2.B.3 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 ($\Delta \hat{x}_t = \hat{x}_t - \hat{x}_{t-1}$). $\tilde{\kappa}$ denotes the slope of the Phillips curve, which is related to the structural parameters β , γ , μ and θ according to $\tilde{\kappa} = (1 - \beta\theta)(1 - \theta)/[1/\theta(1 - \mu + \mu/\gamma)]$. We introduce also $\hat{\Omega} \equiv \bar{b}_H \hat{b}_{H,t} + \bar{E}_t \bar{b}_F \hat{b}_{F,t}$.

$$\hat{\lambda}_t = \frac{(-\sigma_c)}{\bar{c} (1 - h) - \frac{1}{1+\sigma_l} (\bar{l})^{1+\sigma_l}} \left(\bar{c} \hat{c}_t - (\bar{l})^{1+\sigma_l} \hat{l}_t \right) \quad (2.B.48)$$

$$\hat{\lambda}_t^* = \frac{(-\sigma_c)}{(1 - h) \bar{c}^* - \frac{1}{1+\sigma_l} (\bar{l}^*)^{1+\sigma_l}} \left(\bar{c}^* \hat{c}_t^* - (\bar{l}^*)^{1+\sigma_l} \hat{l}_t^* \right) \quad (2.B.49)$$

2.B. Model appendix

$$\hat{\lambda}_t = \hat{R}_t^e - \mathbb{E}_t \hat{\Pi}_{t+1} + (1 - \bar{d}) \mathbb{E}_t \hat{\lambda}_{t+1} + \bar{d} \left(\mathbb{E}_t \hat{\lambda}_{t+1}^* + \mathbb{E}_t \hat{E}_{r,t+1} \right) \quad (2.B.50)$$

$$\hat{\lambda}_t^* = \hat{R}_t^{e*} - \mathbb{E}_t \hat{\Pi}_{t+1}^* + \hat{\lambda}_{t+1}^* (1 - \bar{d}^*) + \bar{d}^* \left(\mathbb{E}_t \hat{\lambda}_{t+1} - \mathbb{E}_t \hat{E}_{r,t+1} \right) \quad (2.B.51)$$

$$\begin{aligned} \hat{R}_t^e &= \hat{R}_t^{e*} - \mathbb{E}_t \hat{e}_{t+1} + \hat{e}_t - \frac{\mathbb{K} n}{n + 1/\bar{E}_r (1 - n)} \left(\hat{\Omega}_t - (\bar{b}_F/\bar{E}_r - \bar{b}_H) \widehat{E}_{rt} \right. \\ &\quad \left. + \bar{b}_H (\hat{n}_t - \hat{n}_t^*) \right) \end{aligned} \quad (2.B.52)$$

$$\begin{aligned} \bar{b} (\hat{n}_{t-1} + \frac{1}{\bar{b}_F/\bar{E}_r + \bar{b}_H} (\hat{\Omega}_{t-1} + \bar{b}_H (\hat{R}_{t-1} - \hat{\Pi}_t) + \bar{b}_F/\bar{E}_r (-\hat{E}_{rt} + \hat{R}_{t-1}^* \\ - \hat{\Pi}_t^*)) - \frac{1}{1 - \bar{d} - \bar{d}^*} (\bar{d} \hat{d}_t + \bar{d}^* \hat{d}_t^*)) = \hat{\Omega}_t - \bar{y} \frac{\bar{P}_H}{\bar{P}} \left(\hat{y}_t + \alpha \left(\frac{\bar{P}_F}{\bar{P}} \right)^{1-\epsilon} \widehat{ToT}_t \right) \end{aligned} \quad (2.B.53)$$

$$\begin{aligned} \hat{d}_t &= (1 - \bar{d} - \bar{d}^*) \beta \mathbb{E}_t \hat{d}_{t+1} + \frac{1 - \bar{d}}{\psi} \left((\bar{c}^* (\hat{c}_t^* - h \hat{c}_{t-1}^*) - (\bar{l}^*)^{1+\sigma_l} \hat{l}_t^*) \bar{\lambda}^* \right. \\ &\quad \left. - (\bar{c} (\hat{c}_t - h \hat{c}_{t-1}) - (\bar{l})^{1+\sigma_l} \hat{l}_t) \bar{\lambda} \right) \end{aligned} \quad (2.B.54)$$

$$\begin{aligned} \hat{d}_t^* &= (1 - \bar{d} - \bar{d}^*) \beta \mathbb{E}_t \hat{d}_{t+1}^* - \left((\bar{c}^* (\hat{c}_t^* - h \hat{c}_{t-1}^*) - (\bar{l}^*)^{1+\sigma_l} \hat{l}_t^*) \bar{\lambda}^* \right. \\ &\quad \left. - (\bar{c} (\hat{c}_t - h \hat{c}_{t-1}) - (\bar{l})^{1+\sigma_l} \hat{l}_t) \bar{\lambda} \right) \frac{1 - \bar{d}^*}{\psi^*} \end{aligned} \quad (2.B.55)$$

$$\hat{n}_t = (1 - \bar{d}) \hat{n}_{t-1} + \bar{d} \hat{n}_{t-1}^* - \bar{d} \hat{d}_t + \bar{d} \hat{d}_t^* \quad (2.B.56)$$

$$\hat{n}_t^* = \hat{n}_t \frac{-n}{1 - n} \quad (2.B.57)$$

$$\begin{aligned} \hat{\Pi}_{H,t} &= \beta \mathbb{E}_t \hat{\Pi}_{H,t+1} + \tilde{\kappa} \left(-\alpha \left(\frac{\bar{P}_F}{\bar{P}} \right)^{1-\epsilon} \widehat{ToT}_t - \hat{y}_t + \hat{w}_t \right. \\ &\quad \left. + \frac{1}{\gamma} (\hat{y}_t - \hat{A}_t) \right) + \epsilon_t^g \end{aligned} \quad (2.B.58)$$

$$\begin{aligned} \hat{\Pi}_{F,t} &= \beta \mathbb{E}_t \hat{\Pi}_{F,t+1} + \tilde{\kappa} \left(\alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*} \right)^{1-\epsilon^*} \right) - \hat{y}_t^* + \hat{w}_t^* \\ &\quad + \frac{1}{\gamma} (\hat{y}_t^* - \hat{A}_t^*) + \epsilon_t^{g*} \end{aligned} \quad (2.B.59)$$

$$\widehat{ToT}_t \left(1 - \alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*} \right)^{1-\epsilon^*} - \alpha \left(\frac{\bar{P}_F}{\bar{P}} \right)^{1-\epsilon} \right) = \hat{E}_{r,t} \quad (2.B.60)$$

$$\hat{\Pi}_{H,t} = \hat{\Pi}_t + \alpha \left(\frac{\bar{P}_F}{\bar{P}} \right)^{1-\epsilon} \left(\widehat{ToT}_t - \widehat{ToT}_{t-1} \right) \quad (2.B.61)$$

$$\hat{\Pi}_{F,t} = \hat{\Pi}_t^* - \alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*} \right)^{1-\epsilon^*} \left(\widehat{ToT}_t - \widehat{ToT}_{t-1} \right) \quad (2.B.62)$$

2.B. Model appendix

$$\hat{y}_t = \frac{\bar{c}}{\bar{y}} (1 - \alpha) \frac{\bar{P}_H}{\bar{P}}^{-\epsilon} (\hat{c}_t + \hat{n}_t) + \frac{(1-n)\bar{c}^* \frac{\bar{P}_H}{\bar{P}}^{-\epsilon}}{\bar{y} \bar{E}_r^\epsilon} \alpha^* (\hat{c}_t^* + \hat{n}_t^* - \hat{E}_{rt} \epsilon) \quad (2.B.63)$$

$$- \widehat{ToT}_t \frac{\alpha \left(\frac{\bar{P}_F}{\bar{P}}\right)^{1-\epsilon}}{\bar{y}} \left(\frac{\bar{P}_H}{\bar{P}}^{-\epsilon} (1 - \alpha) n \bar{c} \epsilon + 1/\bar{E}_r^\epsilon \alpha^* (1 - n) \frac{\bar{P}_H}{\bar{P}}^{-\epsilon} \bar{c}^* \epsilon \right)$$

$$\hat{y}_t^* = (\hat{c}_t^* + \hat{n}_t^*) \frac{\bar{c}^*}{\bar{y}^*} (1 - \alpha^*) \frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} + \frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} \alpha \frac{\bar{c} n}{1-n} \frac{\bar{E}_r^\epsilon}{\bar{y}^*} (\hat{c}_t + \hat{n}_t + \hat{E}_{rt} \epsilon) \quad (2.B.64)$$

$$+ \widehat{ToT}_t \frac{\alpha^* \left(\frac{\bar{P}_H^*}{\bar{P}^*}\right)^{1-\epsilon}}{\bar{y}^*} \left(\frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} (1 - \alpha^*) (1 - n) \bar{c}^* \epsilon + \frac{\bar{P}_F^*}{\bar{P}^*}^{-\epsilon} \alpha n \bar{c} \epsilon \bar{E}_r^\epsilon \right)$$

$$\hat{R}_t = \hat{R}_{t-1} \rho^R + \hat{y}_t (1 - \rho^R) \Phi^y - \hat{e}_t (1 - \rho^R) \Phi^e - (1 - \rho^R) \Phi^g \hat{\gamma}_t + \epsilon_t^r \quad (2.B.65)$$

$$\hat{R}_t^* = \hat{R}_{t-1}^* \rho^{R^*} + \hat{y}_t^* (1 - \rho^{R^*}) \Phi^{y^*} + (1 - \rho^{R^*}) \Phi^{e^*} \hat{e}_t - (1 - \rho^{R^*}) \Phi^{g^*} \hat{\gamma}_t^* + \epsilon_t^{r^*} \quad (2.B.66)$$

$$\hat{R}_t^e = \hat{R}_t + \epsilon_t^b \quad (2.B.67)$$

$$\hat{R}_t^{e^*} = \hat{R}_t^* + \epsilon_t^{b^*} \quad (2.B.68)$$

$$\Delta \hat{G}_t \frac{\bar{G}}{1 + \frac{\bar{G}}{\bar{G}^*}} = \hat{e}_t \epsilon^e + \epsilon_t^m \quad (2.B.69)$$

$$\Delta \hat{G}_t^* \frac{1}{1 + \frac{\bar{G}}{\bar{G}^*}} = \hat{e}_t (-\epsilon^e) + \epsilon_t^{m^*} \quad (2.B.70)$$

$$\Delta \widehat{M}_t = \hat{y}_t + \hat{\Pi}_{H,t} - \hat{y}_{t-1} - v^r (\hat{R}_t - \hat{R}_{t-1}) - \Delta \epsilon_t^\chi \quad (2.B.71)$$

$$\Delta \widehat{M}_t^* = \hat{y}_t^* + \hat{\Pi}_{F,t} - \hat{y}_{t-1}^* - v^r (\hat{R}_t^* - \hat{R}_{t-1}^*) - \Delta \epsilon_t^{\chi^*} \quad (2.B.72)$$

$$\hat{\gamma}_t = \Delta \hat{G}_t + \hat{\gamma}_{t-1} - \Delta \widehat{M}_t \quad (2.B.73)$$

$$\hat{\gamma}_t^* = \Delta \hat{G}_t^* + \hat{\gamma}_{t-1}^* - \Delta \widehat{M}_t^* \quad (2.B.74)$$

$$\hat{E}_{r,t} = \hat{\Pi}_t^* - \hat{e}_t - \hat{E}_{r,t-1} + \hat{e}_{t-1} - \hat{\Pi}_t \quad (2.B.75)$$

$$\hat{t}b_t \bar{t}b = \left(\hat{y}_t + \widehat{ToT}_t \alpha \left(\frac{\bar{P}_F}{\bar{P}}\right)^{1-\epsilon} \right) n \bar{y} \frac{\bar{P}_H}{\bar{P}} - (\hat{c}_t + \hat{n}_t) \bar{c} n \quad (2.B.76)$$

$$\hat{n}_t - \hat{n}_{t-1} = \bar{d} (\hat{d}_t^* + \hat{n}_{t-1}^* - \hat{d}_t - \hat{n}_{t-1}) \quad (2.B.77)$$

$$\hat{n}_t^* - \hat{n}_{t-1}^* = \bar{d}^* (\hat{n}_{t-1} + \hat{d}_t + (-\hat{d}_t^*) - \hat{n}_{t-1}^*) \quad (2.B.78)$$

2.B. Model appendix

$$\hat{w}_t = \sigma_l \hat{l}_t \quad (2.B.79)$$

$$\hat{w}_t^* = \sigma_l \hat{l}_t^* \quad (2.B.80)$$

$$\hat{l}_t = \frac{1}{\gamma} (\hat{y}_t - \hat{A}_t) - \hat{n}_t \quad (2.B.81)$$

$$\hat{l}_t^* = \frac{1}{\gamma} (\hat{y}_t^* - \hat{A}_t^*) - \hat{n}_t^* \quad (2.B.82)$$

$$\hat{A}_t = \rho^a \hat{A}_{t-1} - \eta_t^A \quad (2.B.83)$$

$$\hat{A}_t^* = \rho^{a^*} \hat{A}_{t-1}^* - \eta_t^{A^*} \quad (2.B.84)$$

$$\epsilon_t^r = \rho^{\epsilon^R} \epsilon_{t-1}^r - \eta_t^R \quad (2.B.85)$$

$$\epsilon_t^{r^*} = \rho^{\epsilon^{R^*}} \epsilon_{t-1}^{r^*} - \eta_t^{R^*} \quad (2.B.86)$$

$$\epsilon_t^g = \rho^g \epsilon_{t-1}^g - \eta_t^g \quad (2.B.87)$$

$$\epsilon_t^{g^*} = \rho^{g^*} \epsilon_{t-1}^{g^*} - \eta_t^{g^*} \quad (2.B.88)$$

$$\epsilon_t^m = \rho_m \epsilon_{t-1}^m - \eta_t^m \quad (2.B.89)$$

$$\epsilon_t^{m^*} = \rho_m^* \epsilon_{t-1}^{m^*} - \eta_t^{m^*} \quad (2.B.90)$$

$$\epsilon_t^X = \rho^X \epsilon_{t-1}^X - \eta_t^X \quad (2.B.91)$$

$$\epsilon_t^{X^*} = \rho^{X^*} \epsilon_{t-1}^{X^*} - \eta_t^{X^*} \quad (2.B.92)$$

$$(2.B.93)$$

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 (2.B.65) by the following equation

$$\hat{R}_t^e = \hat{R}_t^{e^*} - \frac{Kn}{n + \bar{E}_r (1 - n)} \left[\bar{b}_H (\hat{b}_{H,t} - \hat{E}_{r,t} + \hat{n}_t - \hat{n}_t^*) + \bar{b}_F \bar{E}_r (\hat{b}_{F,t} + \hat{E}_{r,t}) \right] + \tilde{\phi}_e \hat{e}_t \quad ,$$

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 $\tilde{\phi}_e = 0.01$.

2.B.4 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.⁷⁴ Finally, counterfactual simulations based on an estimated version of the extended model also constitute a robustness check for the papers main result (see Appendix 2.C.3.6).

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 itself (e.g. grain) and local services (e.g. utility

⁷⁴The extension is an adapted version of the model developed in Berka et al. (forthcoming).

2.B. Model appendix

and financial services). The home consumption of imported goods is defined as $c_{F,t} = \left[\check{\phi}^{\frac{1}{\check{\psi}^*}} I_{F,t}^{\frac{\check{\psi}^*-1}{\check{\psi}^*}} + (1 - \check{\phi})^{\frac{1}{\check{\psi}^*}} V_{F,t}^{\frac{\check{\psi}^*-1}{\check{\psi}^*}} \right]^{\frac{\check{\psi}^*}{\check{\psi}^*-1}}$, 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:

$$I_{H,t} = \left(\left(\frac{1}{n} \right)^{\frac{1}{\mu}} \int_0^n I_{H,t}(j)^{\frac{\mu-1}{\mu}} \mathrm{d}j \right)^{\frac{\mu}{\mu-1}}, I_{F,t} = \left(\left(\frac{1}{1-n} \right)^{\frac{1}{\mu}} \int_n^1 I_{F,t}(j)^{\frac{\mu-1}{\mu}} \mathrm{d}j \right)^{\frac{\mu}{\mu-1}},$$

$$V_{H,t} = \left(\left(\frac{1}{n} \right)^{\frac{1}{\mu}} \int_0^n V_{H,t}(j)^{\frac{\mu-1}{\mu}} \mathrm{d}j \right)^{\frac{\mu}{\mu-1}}, V_{F,t} = \left(\left(\frac{1}{1-n} \right)^{\frac{1}{\mu}} \int_n^1 V_{F,t}(j)^{\frac{\mu-1}{\mu}} \mathrm{d}j \right)^{\frac{\mu}{\mu-1}},$$

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-

2.B. Model appendix

tradable goods are $P_{N,t} = \left[\frac{1}{n} \int_0^n P_{N,t}(j)^{1-\mu} dj \right]^{\frac{1}{1-\mu}}$ and $P_{N,t}^* = \left[\frac{1}{1-n} \int_n^1 P_{N,t}^*(j)^{1-\mu} dj \right]^{\frac{1}{1-\mu}}$. 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

$$\max_{P_{H,t}(j)} \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ (\beta\theta_T)^k \frac{\lambda_{t+k}}{\lambda_t} \frac{P_t}{P_{t+k}} \left[P_{H,t}(j) y_{T,t+k}(j) - w_{t+k} P_{t+k} l_{T,t+k}(j) \right] \right\} \quad (2.B.94)$$

$$\text{s.t. } y_{T,t+k}(j) = \left(\frac{P_{H,t}(j)}{P_{H,t+k}} \right)^{-\mu} y_{T,t+k} \quad (2.B.95)$$

$$y_{T,t+k}(j) = A_{t+k} l_{T,t+k}^{\gamma}(j) \quad (2.B.96)$$

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:

$$\Delta_{T,t}^P n y_{T,t}^{\frac{1}{\gamma}} = l_{T,t} n_t A_t^{\frac{1}{\gamma}} \quad (2.B.97)$$

$$\Delta_{N,t}^P n y_{N,t}^{\frac{1}{\gamma}} = l_{N,t} n_t A_{N,t}^{\frac{1}{\gamma}} \quad (2.B.98)$$

$$l_t = l_{T,t} + l_{N,t}, \quad (2.B.99)$$

with the measures for price dispersion

2.B. Model appendix

$$\Delta_{T,t}^P = \frac{1}{n} \int_0^n \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{\frac{-\mu}{\gamma}} dj \text{ and } \Delta_{N,t}^P = \frac{1}{n} \int_0^n \left(\frac{P_{N,t}(j)}{P_{N,t}} \right)^{\frac{-\mu}{\gamma}} dj.$$

The goods market clearing conditions take into account tradable and non-tradable goods:

$$n y_{T,t}(j) = n_t I_{H,t}(j) + (1 - n_t) I_{H,t}^*(j) \quad (2.B.100)$$

$$n y_{N,t}(j) = n_t c_{N,t}(j) + n_t V_{H,t}(j) + (1 - n_t) V_{H,t}^*(j) \quad (2.B.101)$$

$$(1 - n) y_{T,t}^*(j) = n_t I_{F,t}(j) + (1 - n_t) I_{F,t}^*(j) \quad (2.B.102)$$

$$(1 - n) y_{N,t}^*(j) = (1 - n_t) c_{N,t}^*(j) + (1 - n_t) V_{F,t}^*(j) + n_t V_{F,t}(j) \quad (2.B.103)$$

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 2.7 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

$$\widehat{ToT}_t = \hat{P}_{H,t}^* - \hat{P}_{F,t}.$$

The CPI in the extended model can also be written as follows (see (2.5) in the main text):

$$\hat{P}_t = (1 - \check{\gamma}) \hat{P}_{N,t} + \check{\gamma} \left[\check{\alpha} \hat{P}_{H,t} + (1 - \check{\alpha}) \hat{P}_{F,t} \right],$$

with $\check{\gamma} \equiv \tilde{\gamma} \left(\frac{P_T}{P} \right)^{1-\bar{\lambda}}$ and $\check{\alpha} \equiv \tilde{\alpha} \left(\frac{\hat{P}_H}{P_T} \right)^{1-\bar{\epsilon}}$.

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

2.B. Model appendix

describe how prices affect H -households' and F -households' demand for imported goods:

$$c_{F,t} = (1 - \tilde{\alpha}) \left(\frac{\tilde{P}_{F,t}}{P_{T,t}} \right)^{-\tilde{\epsilon}} c_{T,t}, \quad c_{H,t}^* = (1 - \tilde{\alpha}^*) \left(\frac{\tilde{P}_{H,t}^*}{P_{T,t}^*} \right)^{-\tilde{\epsilon}^*} c_{T,t}^*.$$

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 2.7, 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 ($EX_t = c_{H,t}^*n_t^*$) in log-linearized form can be written as

$$\begin{aligned} \widehat{EX}_t &= \hat{c}_{T,t}^* + \hat{n}_t^* - \tilde{\epsilon}^* \left(\hat{\tilde{P}}_{H,t}^* - \hat{P}_{T,t}^* \right) \\ &= \hat{c}_{T,t}^* + \hat{n}_t^* - \tilde{\epsilon}^* \tilde{\alpha}^* \left(\frac{\tilde{P}_F^*}{P_T^*} \right)^{1-\tilde{\epsilon}^*} \left(\hat{\tilde{P}}_{H,t}^* - \hat{\tilde{P}}_{F,t}^* \right), \end{aligned}$$

where the second line makes use of the relation

$$\hat{P}_{T,t}^* = \tilde{\alpha}^* \left(\frac{\tilde{P}_F^*}{P_T^*} \right)^{1-\tilde{\epsilon}^*} \hat{\tilde{P}}_{F,t}^* + (1 - \tilde{\alpha}^*) \left(\frac{\tilde{P}_H^*}{P_T^*} \right)^{1-\tilde{\epsilon}^*} \hat{\tilde{P}}_{H,t}^*$$

as well as the steady state definition of P_T^* . A one unit decrease in the H -export price ($\hat{\tilde{P}}_{H,t}^*$) leads to an increase in the foreign demand for H -produced tradable goods of $\tilde{\epsilon}^* \tilde{\alpha}^* \left(\frac{\tilde{P}_F^*}{P_T^*} \right)^{1-\tilde{\epsilon}^*}$. For an equal fall in H -import prices ($\hat{\tilde{P}}_{F,t}$) and H -export prices ($\hat{\tilde{P}}_{H,t}^*$), the increase in

2.B. Model appendix

exports will exceed the increase in imports. The reason for this is that the H -region is smaller than the F -region ($n < 1 - n \equiv n^*$). Absent home bias (i.e. $n = \tilde{\alpha}$ and $n^* = \tilde{\alpha}^*$), 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.⁷⁵

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 2.1, Table 2.3).

The extended model's additional parameters are calibrated as follows: The shares of tradable goods in final consumption ($\tilde{\gamma}, \tilde{\gamma}^*$) 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 ($\tilde{\alpha}, \tilde{\alpha}^*$) 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%.⁷⁶ Thus, a value of 10% for $1 - \tilde{\phi}$ is of the right order of magnitude. For export goods, $\tilde{\phi}$ is chosen to reflect a 40% transportation cost, which implies that the export good consists of 60% tradable wholesale goods.⁷⁷

⁷⁵Only extreme degrees of home bias in the H region, and an extreme preference of the F region for H goods can overturn this.

⁷⁶As $\tilde{\phi}$ 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.

⁷⁷This 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 top of this, international overseas transport under the GS drove another 10 to 20% wedge between origin and destination port prices (see Persson, 2004).

2.B. Model appendix

Concerning the intra-temporal elasticity, we follow Berka et al. (forthcoming) in assuming an elasticity of substitution between tradable goods and non-tradable goods of 0.7 ($\tilde{\lambda} = \tilde{\lambda}^* = 0.7$), an elasticity of substitution between tradable goods and services of 0.25 ($\tilde{\psi} = \tilde{\psi}^* = 0.25$), and a trade elasticity of 8 ($\tilde{\epsilon} = \tilde{\epsilon}^* = 8$).⁷⁸

The introduction of a sectoral structure also results in four Phillips curves, that determine the price evolution of $P_{H,t}$, $P_{N,t}$, $P_{H,t}^*$, and $P_{N,t}^*$. To reflect the price rigidity in the non-tradable sector, we set the Phillips curve slopes for the non-tradable goods $\tilde{\kappa}_N$, and $\tilde{\kappa}_N^*$ 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 $\tilde{\kappa}_T = \tilde{\kappa}_T^* = 0.65$.

The simulation results are presented in Table 2.12. 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 2.12 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).

⁷⁸The 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 et al., 2017).

2.B. Model appendix

Table 2.12: Correlation between external adjustments, sectoral size and prices

	Δ CA / GDP	
	Model	Data
<i>Panel A: Sectoral sizes</i>		
Δ Tradable sector share	0.49	0.11
Δ Non-tradable sector share	-0.49	-0.08
<i>Panel B: Sectoral prices</i>		
Δ Tradable prices	-0.36	-0.22
Δ Non-tradable prices	0.16	-0.05
<i>Panel C: ToT and CPI</i>		
Δ Terms of trade	-0.11	0.07
Δ CPI	-0.21	-0.15
<i>Panel D: Export and import prices</i>		
	Δ Export prices	
Δ Import prices	0.52	0.59

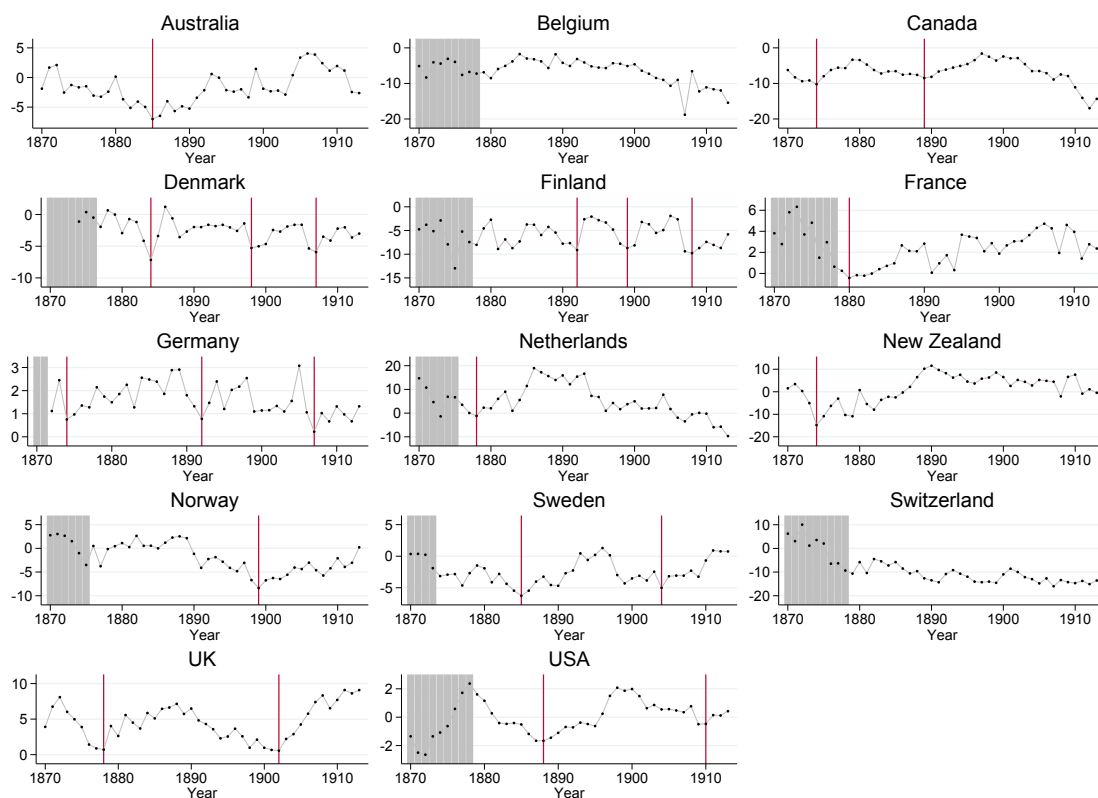
Notes: The model moments are calculated on the basis of 2000 34-year simulations of the extended model. For more details on the stochastic simulation, see Section 2.6. Non-tradable sector share was approximated by tertiary sector share. Tradable sector share was approximated by primary sector share. Tradable prices were approximated by agricultural and raw material prices. Non-tradable prices were approximated by service sector prices.

2.C. Additional results

2.C Additional results

2.C.1 Alternative adjustment periods

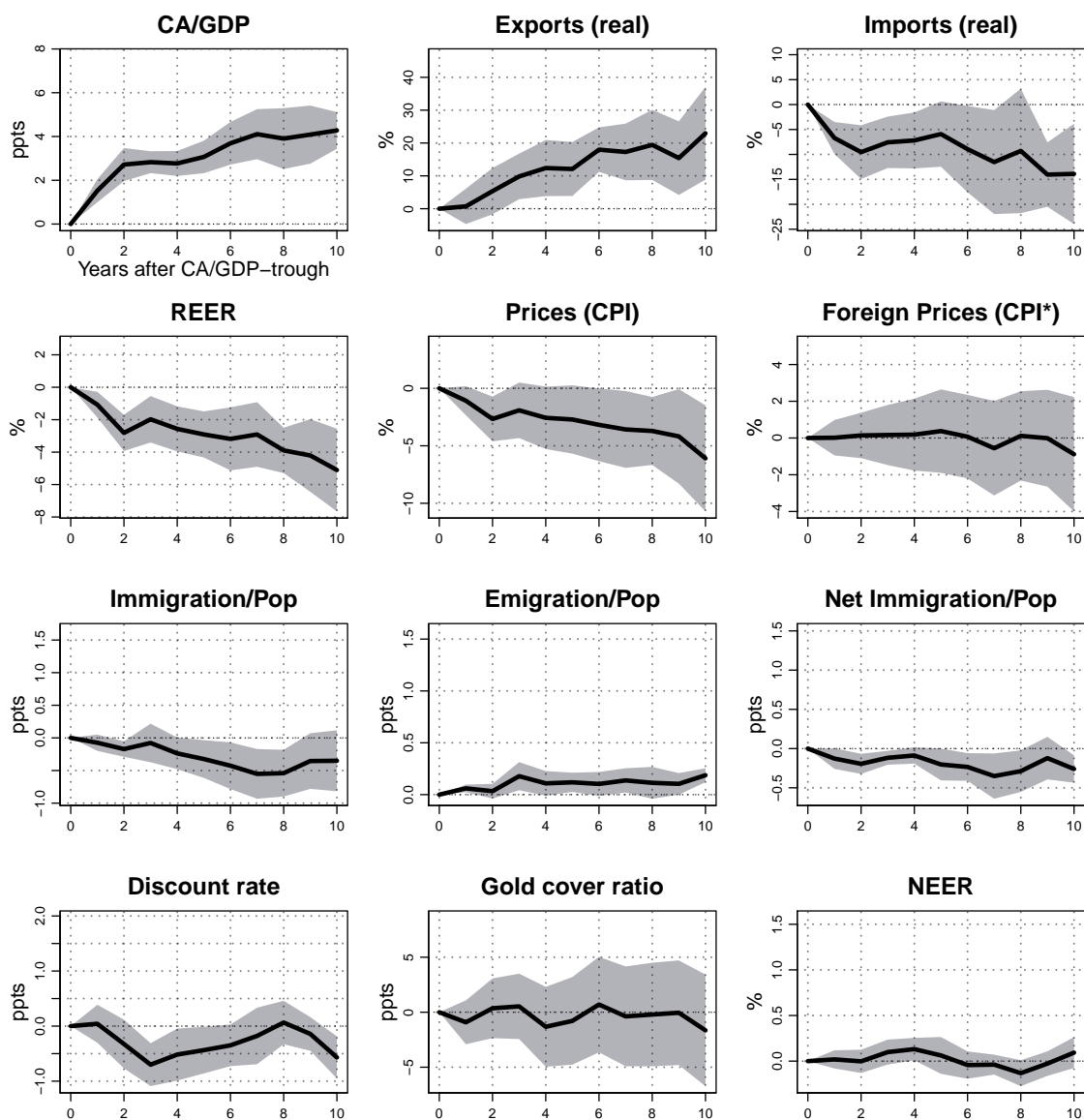
Figure 2.14: CA/GDP within the Gold Standard



Notes: Grey – not on Gold Standard. Vertical bar – CA/GDP trough. CA/GDP troughs are informally defined as all visually salient CA/GDP troughs.

2.C. Additional results

Figure 2.15: 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 2.C.1).

2.C. Additional results

Figure 2.16: Alternative adjustment periods: sectoral prices and sectoral exports

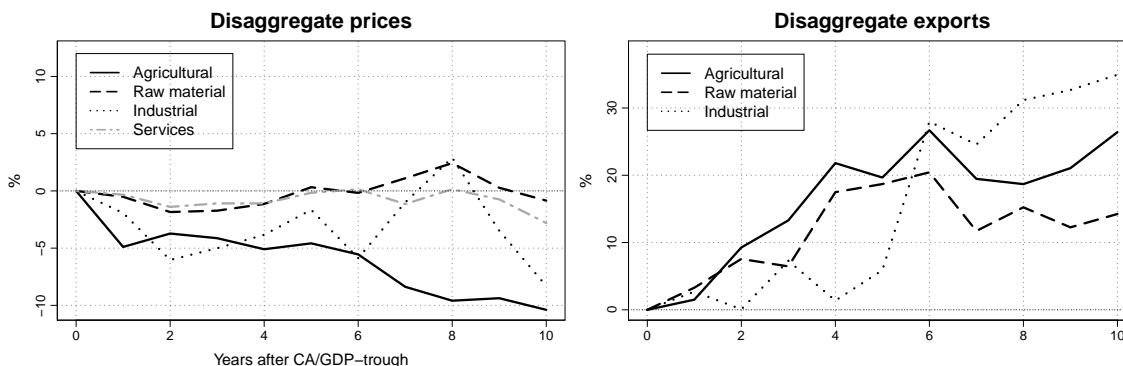


Figure 2.17: Alternative adjustment periods: terms of trade vs. local prices

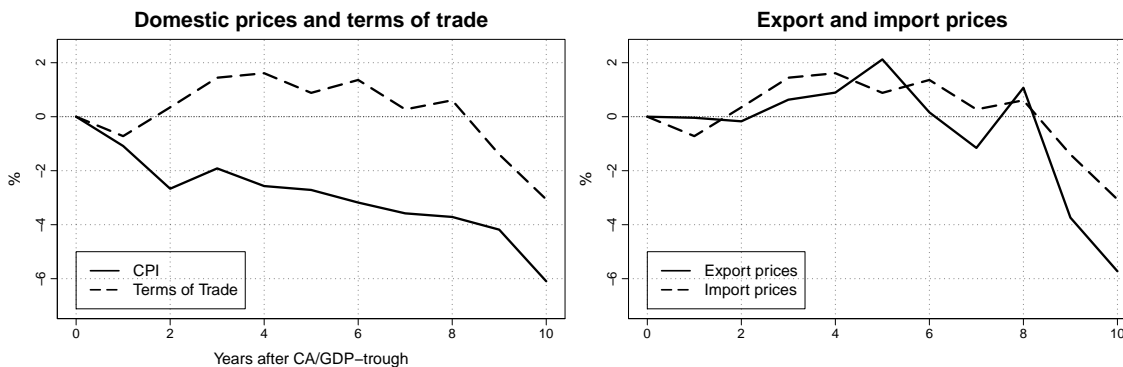
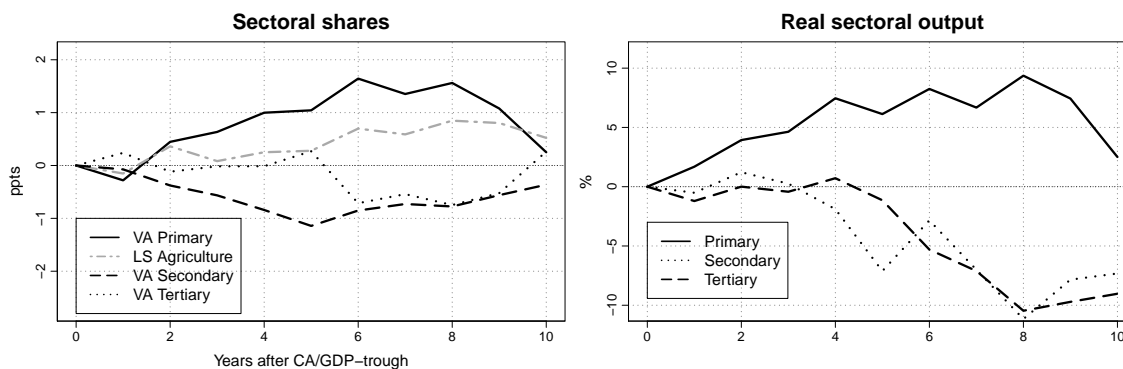


Figure 2.18: Alternative adjustment periods: sectoral adjustment



Notes: CA/GDP troughs are informally defined as all visually salient CA/GDP troughs (see Figure 2.C.1).

2.C.2 Contemporaneous correlations

Table 2.13: Prices, migration and monetary policy correlation with the trade balance

	Δ CA/GDP		
	ρ	p	N
<i>Prices:</i>			
REER	-0.137***	0.00	596
CPI	-0.158***	0.00	596
CPI*	-0.057	0.17	596
<i>Migration:</i>			
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
<i>Monetary policy:</i>			
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 2.14: Correlation between external adjustment, sectoral prices and sectoral exports

	Δ CA/GDP		
	ρ	p	N
<i>Disaggregate prices:</i>			
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
<i>Disaggregate exports:</i>			
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 2.15: 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 2.16: 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

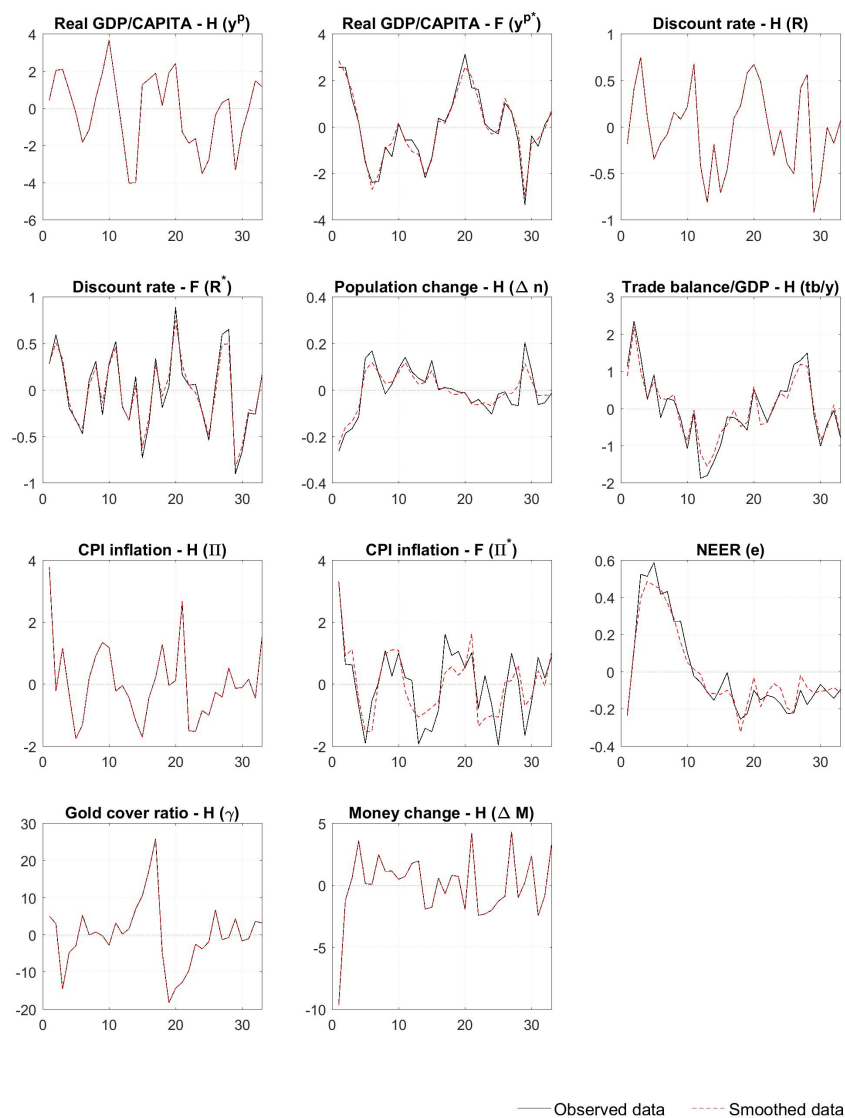
Notes: * 0.10 ** 0.05 *** 0.01. The table shows Pearson correlation coefficients for 2-year changes in the CA/GDP ratio and 2-year changes in the agricultural, industrial and service sector shares.

2.C. Additional results

2.C.3 Additional model results

2.C.3.1 Historical Observations and Smoothed Data

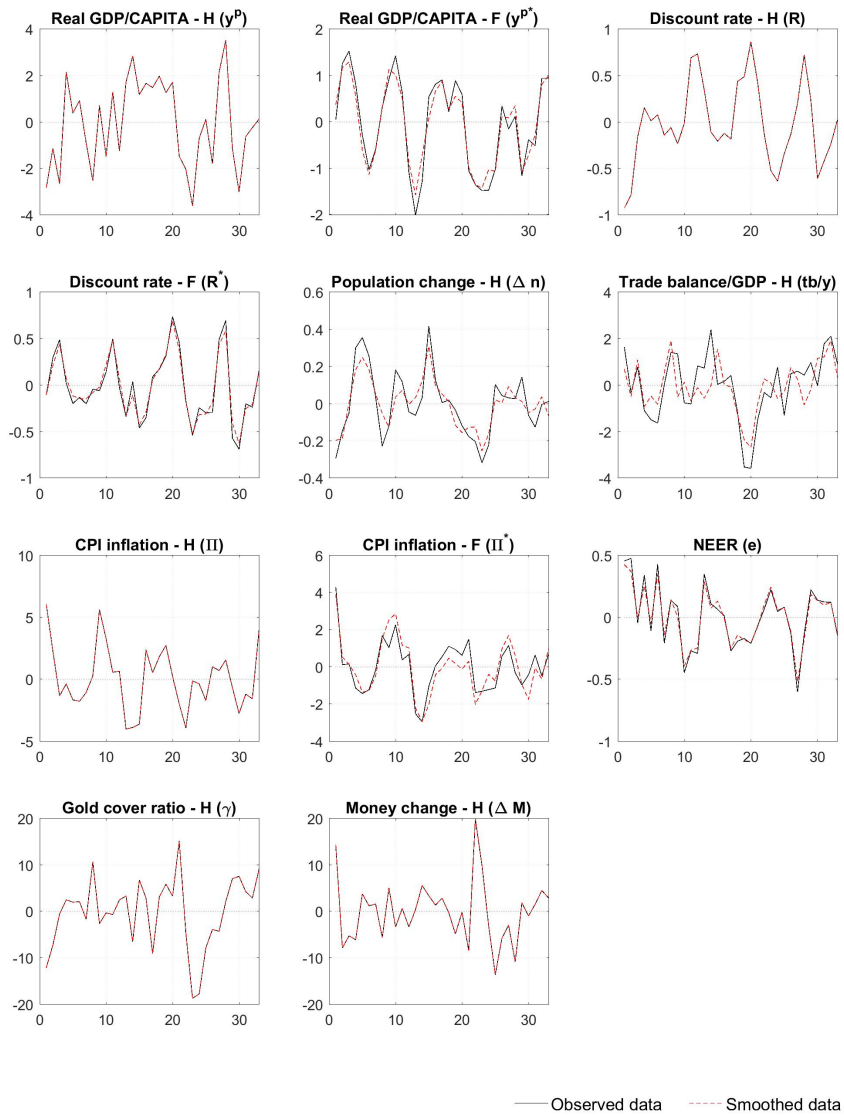
Figure 2.19: Observables and smoothed variables



(a) U.K.

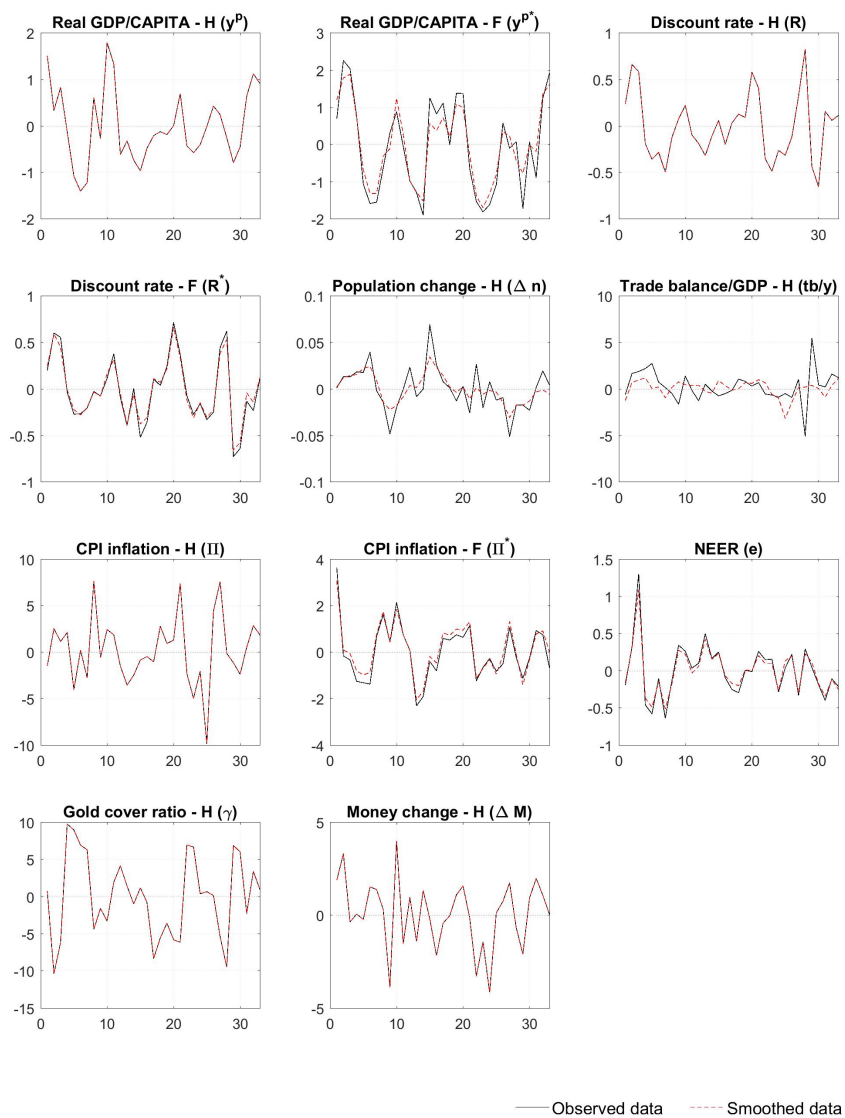
Notes: For variables without measurement error, the smoothed and observed series are identical.

2.C. Additional results



(b) Sweden

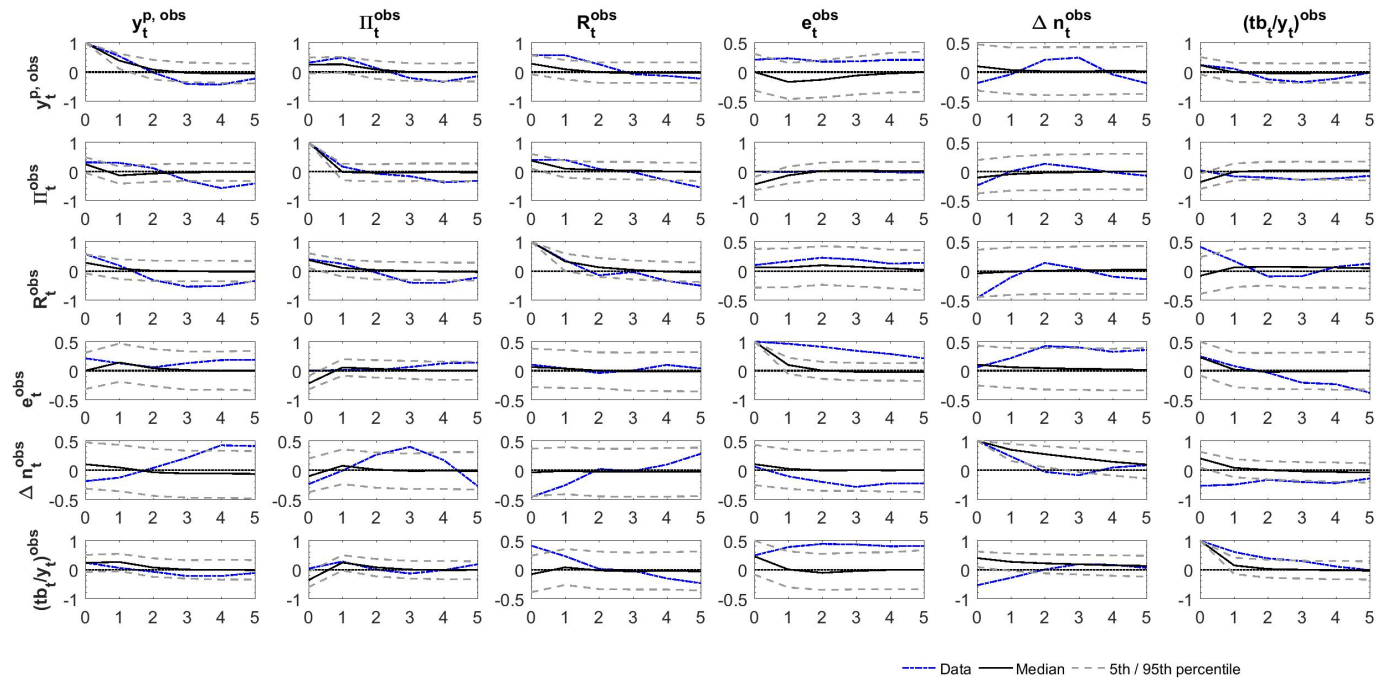
2.C. Additional results



(c) Belgium

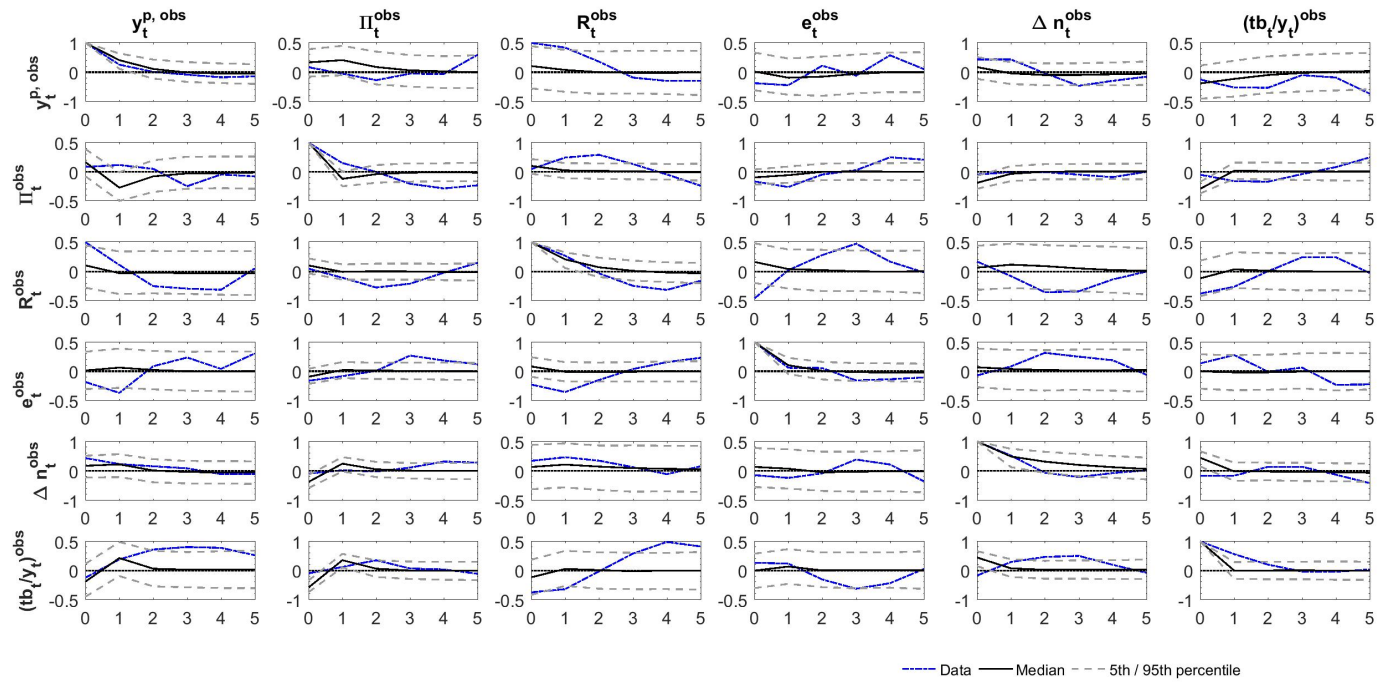
2.C.3.2 Autocorrelations - Observed vs. Simulated Data

Figure 2.21: (Auto-)correlations

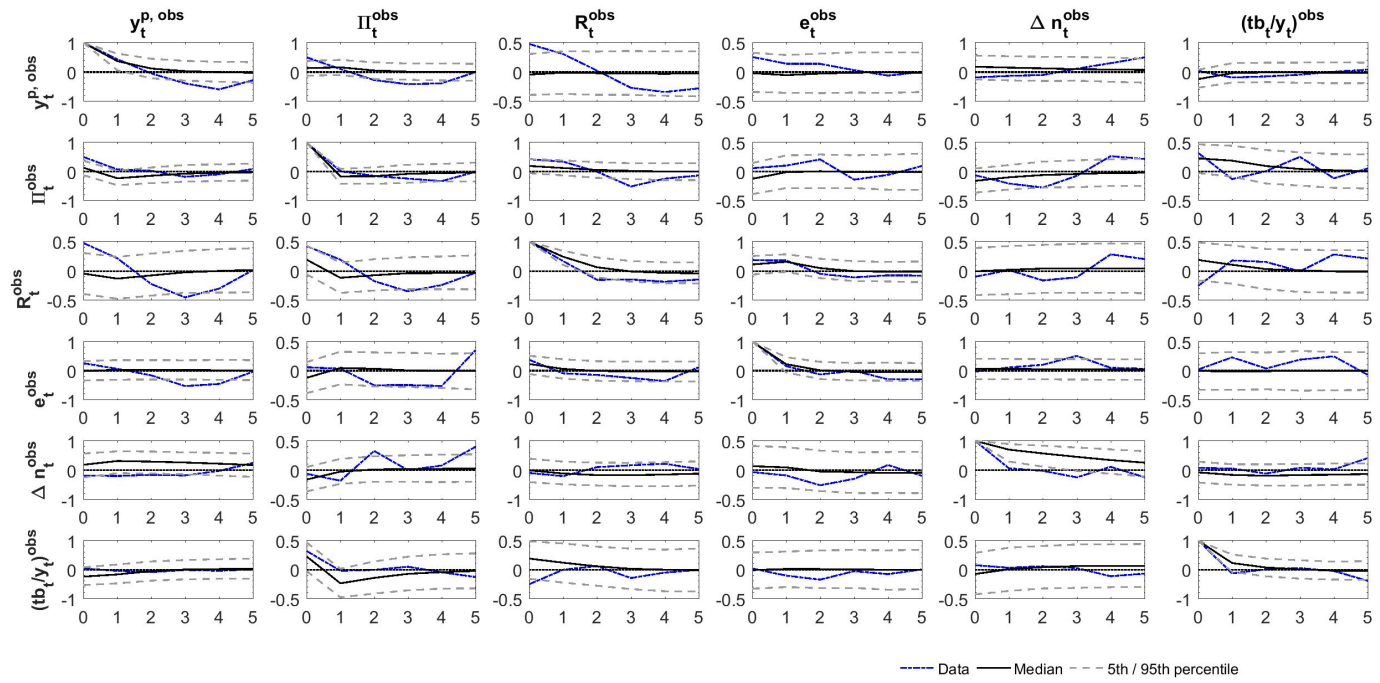


(a) U.K.

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.



(b) Sweden



(c) Belgium

2.C.3.3 Forecast Error Variance Decomposition

Table 2.17: Forecast error variance decomposition

	η^a	η^{a*}	η^r	η^{r*}	η^g	η^{g*}	η^m	η^{m*}	η^x	η^{x*}	η^b	η^{b*}
<i>At 1 year horizon</i>												
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
<i>At 10 years horizon</i>												
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
<i>Unconditional</i>												
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

(a) U.K.

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.

	η^a	η^{a*}	η^r	η^{r*}	η^g	η^{g*}	η^m	η^{m*}	η^x	η^{x*}	η^b	η^{b*}
<i>At 1 year horizon</i>												
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
<i>At 10 years horizon</i>												
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
<i>Unconditional</i>												
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

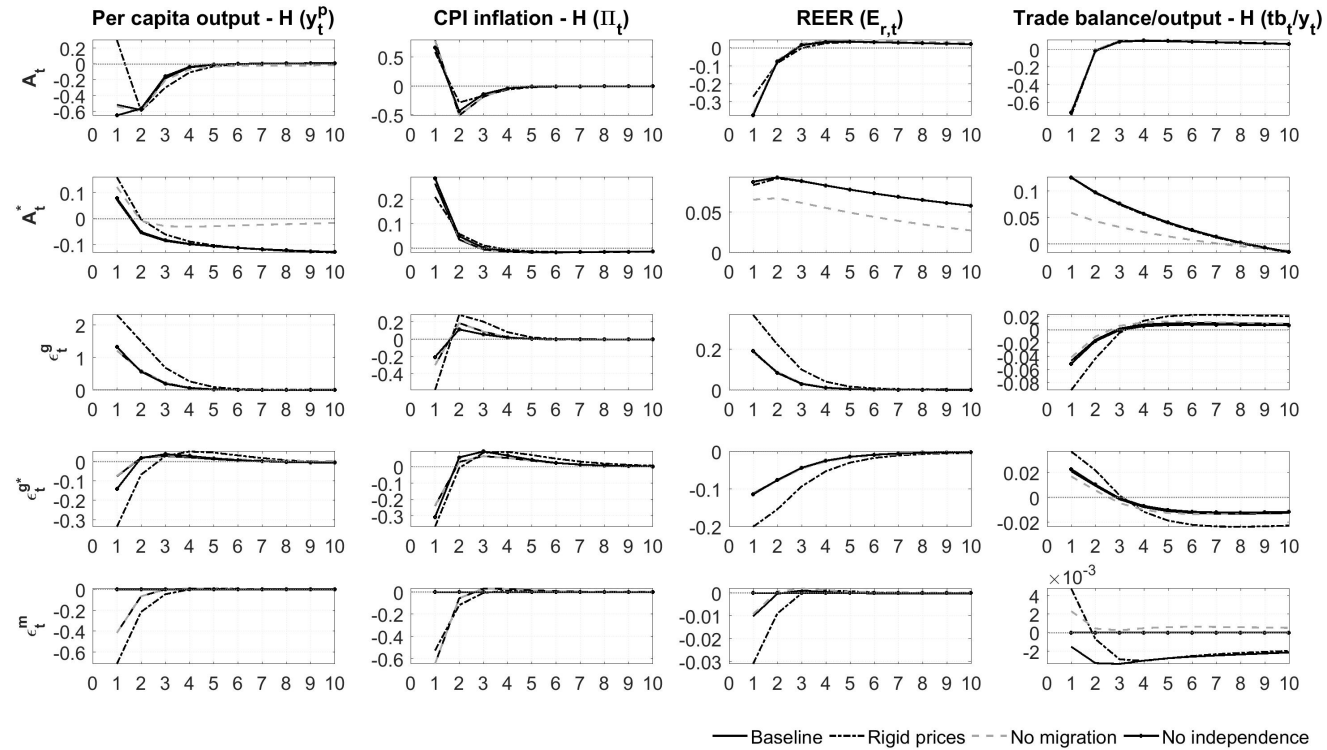
(b) Sweden

	η^a	η^{a*}	η^r	η^{r*}	η^g	η^{g*}	η^m	η^{m*}	η^x	η^{x*}	η^b	η^{b*}
<i>At 1 year horizon</i>												
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
<i>At 10 years horizon</i>												
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
<i>Unconditional</i>												
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

(c) Belgium

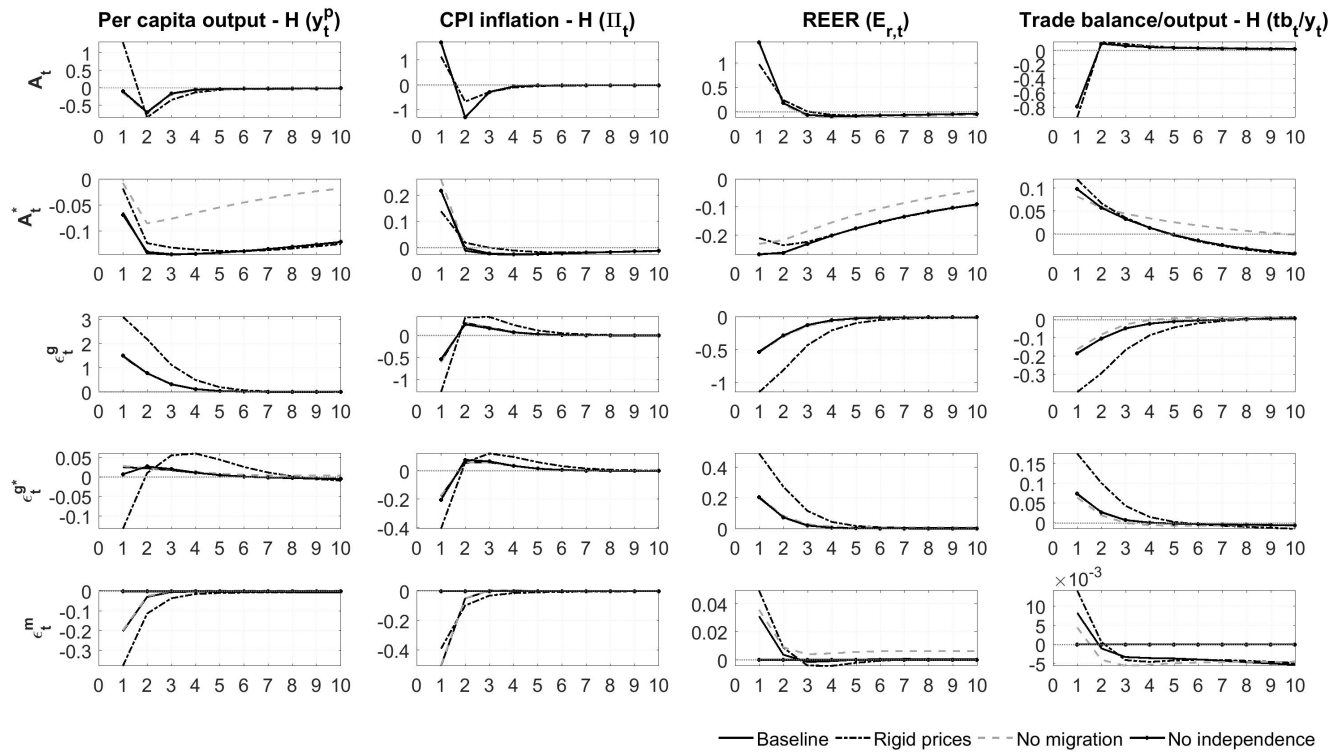
2.C.3.4 Baseline and counterfactual impulse responses

Figure 2.22: Baseline and counterfactual impulse responses

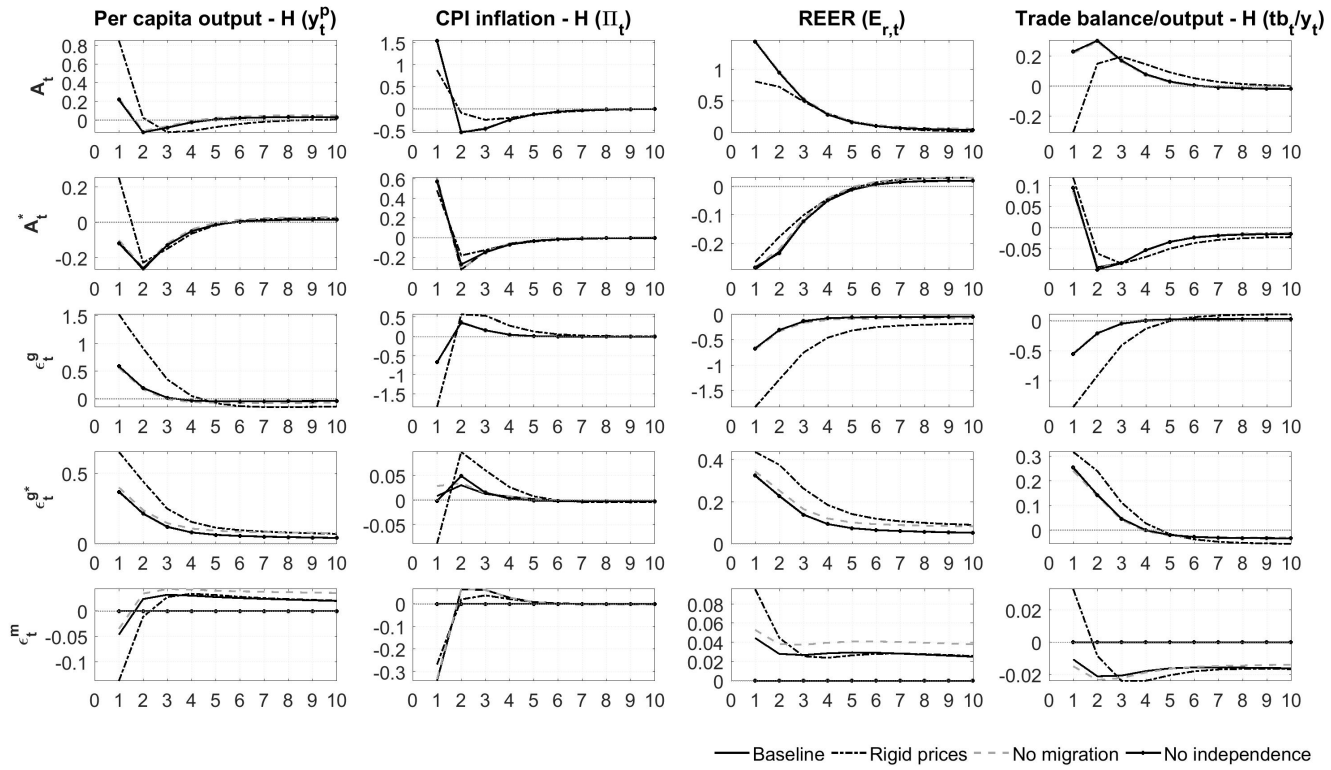


(a) U.K.

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, ϵ_t^{g*} – markup shock F, ϵ_t^m – gold shock.



(b) Sweden



(c) Belgium

2.C. Additional results

2.C.3.5 Additional counterfactual volatilities (baseline model)

Table 2.18: Counterfactual volatility

		Baseline model	Rigid prices	No migration	No inde- pendence	No migration, given rigid prices	No inde- pendence, given rigid prices
		(1)	(2)	(3)	(4)	(3—2)	(4—2)
<i>United Kingdom</i>							
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%)
<i>Sweden</i>							
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%)
<i>Belgium</i>							
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.

2.C. Additional results

2.C.3.6 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 2.19, 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 2.B.4 presents a two-sector version of the GS model. Here we report the

2.C. Additional results

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 $\tilde{\gamma}^*$. Another reason for why $\tilde{\gamma}$ and $\tilde{\gamma}^*$ 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 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 2.19 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

⁷⁹The model calibration is described in Appendix 2.B.4.

⁸⁰One 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).

⁸¹While 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.

2.C. Additional results

those of from other countries' models (see Table 2.19 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, 2016; Bazot et al., 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 2.19 panel D displays the counterfactual simulation results for France. Price flexibility again is the most influential factor when it comes to output stability.

Table 2.19: Counterfactual volatility

	Baseline model	Rigid prices	No migration	No inde- pendence	No migration, given rigid prices	No inde- pendence, given rigid prices
	(1)	(2)	(3)	(4)	(3—2)	(4—2)
<i>Panel A: United Kingdom hybrid</i>						
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%)
<i>Panel B: United Kingdom extended</i>						
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%)
<i>Panel C: Norway</i>						
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%)
<i>Panel D: France</i>						
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.

3

Sovereign Default Risk and the Role of International Transfers

3.1 Introduction

When countries join a currency union, they give up the exchange rate as a tool for business cycle stabilization. A long stream of literature argues that fiscal integration and interregional transfers have to substitute for the lost monetary autonomy.¹ This paper contributes to this discussion by examining interregional risk sharing arrangements in a currency union where member states are afflicted by sovereign default risk. I show that international risk sharing can have a sizable and positive welfare-impact to the extent that it ameliorates severe recessions.

In this paper, I introduce a sovereign default model in which sovereign risk spills over into local private sector financing costs. The concurrence of a large increase in private sector borrowing costs and sovereign debt crises has been widely studied in the context of the euro area debt crisis.² This linkage between public and private sector financing conditions can amplify recessions, and hence opens the door for international risk sharing to have a sizable positive welfare-impact. This is because risk sharing no longer only helps to smooth consumption – the traditional effect of insurance – but by ameliorating the asymmetric risk for severe recessions, it also raises the average consumption level.

The model's setup resembles the sovereign default models of Eaton and Gersovitz (1981) and Arellano (2008). The regional government of a small open economy can issue one-period non-state-contingent bonds on the international financial market. Access to the international market allows the government to smooth the consumption of its economy.

¹See for example the seminal work of Kenen (1969) and more recently Farhi and Werning (forthcoming), and the references therein.

²See for example Committee on the Global Financial System (2011), International Monetary Fund (2013) and Bocola (2016).

3.1. Introduction

However, the government's ability to insure its economy is limited by the incompleteness of the international financial market, as well as the government's inability to commit to debt repayment. In order to reflect the impact of external borrowing costs on the regional economy, I introduce a working capital financing channel to the model, which together with variable capacity utilization endogenously determines output. In this way unfavorable economic conditions that increase the sovereign's default incentive also increase private-sector financing costs, giving rise to the risk for severe recessions.

I use the model to analyze two different balanced-budget international risk sharing arrangements. The arrangements differ with respect to the balance they strike between insuring the small open economy against bad outcomes and instilling it with an incentive not to default. First, I derive the optimal risk sharing scheme and evaluate its effect on output, consumption, and welfare. The optimal insurance scheme features transfers and repayments that vary with the economic conditions of the small open economy, similar to transfers within a fiscal union. The optimal insurance not only serves to smooth consumption, but it also reduces the government's incentive to default on international investors. This positively affects average output, as a lower sovereign default probability lowers the magnitude of recessions. In a quantitative exercise calibrated to Greece, the existence of an optimal insurance scheme ameliorates the output drop by 4% and results in a welfare improvement equivalent to a 1% increase in certainty equivalent consumption.

The optimal risk sharing scheme can be implemented as a state-contingent transfer within a fiscal union. Although the implementation of such a fiscal union in the euro area is often discussed, it still faces noticeable political resistance. In contrast, simpler *standby facilities*, such as the European Stability Mechanism, are already in place. Motivated by this, I proceed to compare the optimal international risk sharing arrangement to a standby facility. The standby facility provides emergency funding in economic downturns and in this way, it lowers the governments' default incentive and helps to ameliorate severe recessions. In contrast to the optimal insurance scheme, however, the standby facility features non-state-contingent repayments. Nevertheless, the existence of a standby facility results in a welfare improvement of up to 0.74% – around three-quarters of the welfare improvement the optimal insurance scheme provides.

What makes the simple standby facility compare so favorably to the optimal insurance scheme? In my setup international risk sharing has two effects. First, it helps to smooth consumption – the traditional effect of insurance. Second, and more importantly, international insurance reduces the asymmetric downside risk for a severe recession that emerges

3.1. Introduction

out of the interaction between sovereign risk spreads and private sector financing costs. It is this second effect of international risk sharing that generates the significant welfare impact. The standby facility, which is redundant except when the economy is facing large negative shocks, has a much more limited capacity to smooth consumption compared to the optimal risk sharing scheme. Nevertheless, the welfare impact of the two risk sharing arrangements is comparable, because just like the optimal insurance scheme the standby facility reduces sovereign default risk and thereby limits the exacerbation of recessions. By ameliorating this risk, the standby facility increases the average level of output and consumption, and thus reaps most of the benefits that an optimal insurance scheme can provide.

The finding that a simple standby facility does comparably well is of practical relevance. When two or more sovereign states consider entering an international risk sharing arrangement the willingness to part with fiscal autonomy is often low. Under such circumstances, the formation of a simple emergency fund can be politically feasible in many cases where deeper fiscal integration is not an option. My findings suggest that the lower degree of fiscal integration has few drawbacks in terms of welfare gains foregone.

This paper is closely related to several strands of the literature. First, my theoretical framework is an extension of the work on sovereign default by Eaton and Gersovitz (1981) and Arellano (2008), who analyze the relationship between default probabilities and output fluctuations in a one-period non-state-contingent debt framework. Chatterjee and Eyigungor (2012) extend the model to incorporate long-term debt. While these papers assume exogenous endowment economies, the endogenous output channel I introduce here is inspired by Mendoza and Yue (2012). An important implication of such an endogenous output channel is that default costs are increasing and convex in output – a relationship that is often modeled in reduced form in previous papers. While these papers explain the business cycle dynamics around default events, my research uses the sovereign default framework to study the role of international risk sharing. DAVIS (forthcoming) also studies risk sharing in a sovereign default setup and shows that sovereign debt crises can be part of the efficient risk sharing arrangement when there are informational friction and limited commitment. This paper focus instead on the quantitative effect of sovereign risk spillover on the role of international risk sharing.

Second, this paper is also related to the literature that examines the role of interregional transfers within a currency union. In a seminal contribution, Kenen (1969) argues that interregional fiscal transfers are essential to offset regional differences and ensure the well-

3.1. Introduction

functioning of a currency union. Eichengreen (1992) points out that the limited commitment problem may be particularly important for euro area member states with high levels of public debt. He predicts that this may necessitate the institutionalization of interregional transfers. My research formalizes and quantitatively evaluates the argument put forward in Eichengreen (1992). More recently, Farhi and Werning (forthcoming) characterize a fiscal union as an optimal risk sharing arrangement within a currency union. They show that a fiscal union is beneficial not only because of market incompleteness but also due to aggregate demand externalities. My paper is complementary to their paper in that it zooms in on limited commitment as a rationale – but also limitation – for interregional insurance.

Third, this paper is related to Corsetti, Kuester, Meier and Müller (2013, 2014), who, against the backdrop of the euro area debt crisis, examine the impact of sovereign risk spillovers on macroeconomic stability and fiscal policy. As in their papers, I assume that sovereign default risk spills into private sector financing costs. Empirical evidence for this spillover is presented by Neri (2013), and International Monetary Fund (2013).³ Bocola (2016) provides a theoretical microfoundation of such a pass-through. He points out that not only do banks with exposure to government bonds suffer losses when the bond price drops, increasing sovereign default risk also generates a precautionary motive for the banks to deleverage. Gennaioli, Martin and Rossi (2014) also develop a theoretical model that characterizes the connection between sovereign defaults and the private financial market through banks' exposure to government bonds. They argue that more developed financial markets translate into a stronger linkage between sovereign defaults and private sector financing conditions. This provides governments with stronger incentives to repay. Furthermore, this paper also speaks to the literature that studies the relationship between sovereign interest rates and private sector activity in emerging markets (see Neumeyer and Perri, 2005; Uribe and Yue, 2006). While in these papers sovereign risk is given exogenously the framework presented here features an endogenous default decision. This is essential for better understanding the interplay between interregional transfers and limited commitment.

Fourth, through my analysis of a standby facility, this paper also adds to the sovereign default literature that zooms in on bailouts. Boz (2011) proposes a framework to analyze the dynamics of lending by International Financial Institutions like the IMF. Kirsch and Rühmkorf (2015) consider how conditional financial assistance affects the default incentive of governments, and Fink and Scholl (2016) evaluate the effectiveness of conditionality in

³See also Lane (2012) for a description on the evolution of the European debt crisis and the interaction between the sovereign debt crisis and the banking crisis.

3.2. Theoretical framework

bailouts. Roch and Uhlig (2016) analyze the role of a bailout guarantee in eliminating self-fulfilling debt crises. Pancrazi, Seoane and Vukotic (2017) examine the welfare effects of bailouts and point out that some bailouts that are welfare improving ex-ante can have detrimental welfare effects ex-post, if recessions are long-lasting. Mueller, Storesletten and Zilibotti (2015) study the interaction between sovereign default, external intervention, and structural reform. Complementary to their study, I show that bailouts can help to ameliorate the impact of negative shocks and that the effectiveness of bailouts is comparable to that of an optimal risk sharing scheme.

The remainder of the paper is organized as follows. Section 2 presents the theoretical framework, Section 3 assesses its quantitative implications, and Section 4 concludes.

3.2 Theoretical framework

In this section, I describe the theoretical framework. The model describes a currency union that consists of a regional and a federal level. On the regional level, there exists a small open economy with three groups of domestic agents. The domestic agents are households, firms and the regional government. There also exists one group of foreign agents, the international investors. On the federal level of the currency union, interregional risk sharing is either provided by the federal planner, in case of the optimal risk sharing scheme or by a simple standby facility.

I outline the framework in three steps. First, I present the baseline model without any risk sharing arrangements. After that, I characterize the optimal risk sharing scheme using an optimization problem of a welfare-maximizing federal planner. Finally, the last part of this section describes the standby facility.

3.2.1 The baseline model

DOMESTIC HOUSEHOLDS

Households choose consumption c_t and labor h_t to maximize their lifetime utility $\mathbb{E} \left[\sum_{t=0}^{\infty} \beta^t u(c_t, h_t) \right]$, where $\beta \in (0, 1)$ is the time discount factor. $u(\cdot)$ is the households' period utility function, which is assumed to have the functional form introduced by Greenwood,

3.2. Theoretical framework

Hercowitz and Huffman (1988) (GHH) ⁴

$$u(c_t, h_t) = \frac{[c_t - h_t^{1+v}/(1+v)]^{1-\sigma} - 1}{1-\sigma}, \text{ with } \sigma, v > 0.$$

The households do not participate directly in the international financial market, but the government can borrow from abroad and pays a lump sum transfer τ_t to the households.⁵ Furthermore, the households have income from working at the market wage w_t as well as from lump sum dividends paid by domestic firms Π_t . The representative household's maximization problem is

$$\begin{aligned} & \max_{\{c_t, h_t\}_{t=0}^{\infty}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_t, h_t) \right] & (3.1) \\ \text{subject to} & \quad c_t - w_t h_t - \tau_t - \Pi_t = 0. \end{aligned}$$

The optimal labor supply satisfies

$$h_t^v = w_t. \quad (3.2)$$

DOMESTIC FIRMS

Domestic firms produce a homogeneous and tradable good with a Cobb-Douglas production function

$$y_t = z_t (u_t K)^{1-\gamma} h_t^\gamma, \text{ with } \gamma > 0. \quad (3.3)$$

z_t is the exogenous productivity level in the economy and it is assumed to follow a J -state Markov process with a transition probability $\mathbb{P}(z_t | z_{t-1})$. $u_t \in (0, 1]$ is a variable level of capacity utilization and K is the time-invariant level of capital. As in Greenwood et al. (1988), King and Rebelo (1999) and Gertler, Gilchrist and Natalucci (2007), capacity utilization is associated with resource costs $\Psi(u_t)$. These costs reflect capital depreciation

⁴The GHH preferences are commonly used in the open economy literature. They remove the wealth effect on labor supply and allow labor supply to display plausible business cycle dynamics. See for example Schmitt-Grohé and Uribe (2003), Neumeyer and Perri (2005), and Mendoza and Yue (2012).

⁵As shown in Na, Schmitt-Grohé, Uribe and Yue (forthcoming), sovereign default models in the tradition of Eaton and Gersovitz (1981), that feature a “government-controlled” allocation, can be decentralized with an appropriate taxation on debt. This is the case also in the model presented here.

3.2. Theoretical framework

and they are increasing in the level of utilization

$$\Psi(u_t) = \Psi + \frac{\delta}{1 + \xi} u_t^{1+\xi}, \text{ with } \Psi, \delta > 0. \quad (3.4)$$

Before sales, firms have to pay for a fraction ϕ of the production costs, i.e. the wage bill and the cost of capacity utilization. To finance this, they take out within-period working capital loans from the domestic financial sector at the net interest rate r_t . Working capital is a mechanism that has been often used in the literature to reflect the role of financial intermediation costs on emerging market business cycles. Firms' profits are

$$\Pi_t = y_t - w_t h_t - K\Psi(u_t) - \phi r_t (w_t h_t + K\Psi(u_t)), \quad (3.5)$$

which are paid out lump sum to domestic households. Firms operate in a perfectly competitive goods market and choose the level of utilization u_t and labor h_t to maximize profits.

This paper differs from the existing literature on sovereign debt default by adding the feature of variable capacity utilization to the production sector. While the capital stock is relatively stable at business cycle frequencies and plays only a limited role in output dynamics around default and sudden stop events, capacity utilization does exhibit pronounced cyclical fluctuations (see for example Mendoza, 2010; Meza and Quintin, 2007; Mendoza and Yue, 2012). As shown by King and Rebelo (1999), capacity utilization can help to amplify the impact of productivity shocks on output. Together with working capital, variable capacity utilization also amplifies the effect of interest rate changes on output.

When the domestic costs of financial intermediation r_t and a productivity realization z_t are taken as given, the (partial) equilibrium in the small open economy is described by the following equations

$$h_t = \left(\frac{1 + \phi r_t}{z_t \tilde{K}} \right)^{1/\tilde{\gamma}}, \quad (3.6)$$

$$u_t = \left(\frac{h_t^{1+v}(1-\gamma)}{K^2 \delta \gamma} \right)^{\frac{1}{1+\xi}}, \quad (3.7)$$

3.2. Theoretical framework

$$y_t = \frac{1}{\gamma} \frac{(1 + \phi r_t)^{1 + \frac{1+v}{\gamma}}}{(z_t \tilde{K})^{\frac{1+v}{\gamma}}}, \quad (3.8)$$

with $\tilde{K} = K^{1-\gamma} \gamma ((1-\gamma)(\gamma K^2 \delta))^{(1-\gamma)/(1+\xi)}$ and $\tilde{\gamma} = -(v\gamma + \xi(1-\gamma+v))/(1+\xi)$. Under the calibration used for the quantitative analysis (see below), output, utilization and labor in equilibrium are increasing in z_t and decreasing in r_t .

A core aspect of my model is the spillover of sovereign risk spreads into private sector financing costs. There exist several papers which assume that interest rates for working capital and sovereign debt spreads comove in emerging markets (Neumeyer and Perri, 2005; Uribe and Yue, 2006). For developed economies, the interplay of sovereign default spreads, private sector financing costs, and business cycles has also recently gained attention, in light of the euro area sovereign debt crisis. Many studies have documented the disruptive effects of the euro area debt crisis on private financial intermediation, as well as the close relationship between sovereign risk spreads and private sector financing costs.⁶ The crisis has also sparked theoretical research on the pass-through of sovereign risk spreads to the private sector (see Bocola, 2016). Let q_t denote the price of the government bonds. $1+r$ is the time-invariant riskfree interest rate, which is also the international investors' opportunity costs of funds (see below). I assume that the private sector intermediation cost r_t depends on the government bond spread $(1/q_t)/(1+r) = 1/((1+r)q_t)$ and the government's access to the international financial market in the following way:

$$1+r_t = \begin{cases} (1+r) \chi \left[\frac{1}{(1+r)q_t} \right]^\alpha & \text{with access to international financial markets,} \\ 1+r^D & \text{without access to international financial markets} \end{cases} \quad (3.9)$$

where $\chi \geq 1$ and $\alpha > 0$, and r^D is the financing cost when the government loses access to the financial market. Whenever the government has access to the international financial market, the cost of financial intermediation is decreasing in the government's bond price.⁷ The government's bond price, in turn, is decreasing in the government's default probability (see below). In other words, an increase in sovereign's default probability leads to an increase in the financing costs of domestic firms. This in turns depresses output through the working

⁶See for example Committee on the Global Financial System (2011).

⁷The assumed functional form resembles the modeling of sovereign risk spillover in Corsetti et al. (2013, 2014).

3.2. Theoretical framework

capital channel and amplifies the effect of negative productivity shock.⁸

If on the other hand, the government has lost access to the international financial market due to its defaulting on its debt, this is assumed to have a detrimental effect on domestic financial intermediation. More precisely, private sector financing costs are assumed to increase to a level r^D much higher than the riskfree rate r . The stress on domestic financial intermediation is assumed to persist for as long as the government is excluded from the international financial market. The implicit assumption here is that the default has a persistent impact on the financial sector's intermediation ability and that regaining access to the international financial market takes about as much time as it takes for the domestic financial system to recover. As the cost of intermediation is constant during the exclusion periods, the equilibrium level of output, labor, and capacity utilization are functions of the productivity level z_t only. These modeling assumptions are a simple way to reflect the economic impact of sovereign default risk and sovereign default.⁹

It is worth pointing out that the output costs of default differ from the output costs usually assumed in the literature. Most of the default literature follows Arellano (2008) in assuming an exogenous default cost that directly affects the productivity level of the economy in autarky.¹⁰ In contrast, the output costs in my model are due to financial stress which results in higher domestic costs of financial intermediation after a default. With the sovereign risk spillover channel, the government's default incentive and debt policy affect private sector credit conditions and hence regional output. This, in turn, is internalized by the government when it faces its decision problem, to which we turn now.

REGIONAL GOVERNMENT

The regional government is benevolent and its objective is to maximize the domestic households' lifetime utility. The government has access to the international financial market, where it can sell one-period non-state-contingent government bonds b_t to international investors. I assume that these investors are risk neutral and that the market for sovereign

⁸Aguiar, Amador and Gopinath (2009) show that limited commitment and high levels of sovereign debt can also increase the cyclicity through the impact on investment.

⁹Note that Mendoza and Yue (2012) study a version of their model where sovereign default risk affects private sector financing costs. They find that this linkage has little quantitative implication. As it will become clear in the quantitative exercise below, the sovereign risk spillover does play a crucial role in the model with variable capacity utilization presented here.

¹⁰See also Chatterjee and Eyigungor (2012) and Arellano and Bai (2016). An exception is Mendoza and Yue (2012), where the costs of default emerge endogenously as a result of an inefficiency on the production side because imported inputs have to be imperfectly replaced with domestically produced inputs.

3.2. Theoretical framework

bonds is competitive. The price of the government bond is $q(b_t, z_t)$ and it depends on the amount of new government bonds issued b_t as well as the current productivity realization of the small open economy z_t . This is described in more detail below. Absent any interregional risk sharing arrangement, the bonds are the only instrument that the government has to smooth domestic households' consumption. However, the government lacks the ability to commit to repay its debt and it may choose to default after observing the productivity level. When the government defaults, it defaults on 100% of the maturing debt and it becomes excluded from the international financial market.¹¹ After the initial default period, the government regains market access with an exogenous probability θ , in which case it starts with zero debt.¹²

Consider the case where the government is not in default. At the beginning of the current period t , the government chooses a debt policy that maximizes households' welfare. The government can either (1) default or (2) repay and decide upon the amount of new debt issuance. Both, the payoff of repayment and that of default consist of the lifetime utility of the households (V^r for repayment and V^d for default) as well as a random component (ϵ_t^r or ϵ_t^d). As we will see soon, the lifetime utility of repayment is a function of the inherited debt level b_{t-1} and the current productivity level z_t . The lifetime utility of default, on the other hand, only depends on the productivity level due to the assumption of full default. The government makes the default decision by comparing the payoff of repayment with the payoff of default:

$$\max \left\{ \underbrace{V^r(b_{t-1}, z_t) - \epsilon_t^r}_{\text{repayment}}, \underbrace{V^d(z_t) - \epsilon_t^d}_{\text{default}} \right\}.$$

It is assumed that if the government is indifferent between repayment and default, it chooses to repay. The stochastic components stand in for political uncertainty in the default decision. They affect the households' preferences over repayment or default and are only observable to the domestic agents.¹³ Tomz and Wright (2007) show that low output can only partly

¹¹In practice observed haircuts in sovereign defaults are often less than 100%, see Sturzenegger and Zettelmeyer (2008) and Cruces and Trebesch (2013).

¹²It is common in the sovereign default literature to assume that the chance of renewed access to international financial markets is an exogenous process. This reflects protracted negotiation processes between the government and its creditors, only after the completion of which the country may borrow again.

¹³The assumption of unobserved shocks that affect outside options has been explored in the sovereign default context, see Aguiar and Amador (2014) and the references therein. An alternative interpretation is based on the random utility approach.

3.2. Theoretical framework

explain governments' default decisions and the literature has considered political factors to play a non-negligible role in default events. Here, without explicitly modeling the political economy of default, I capture the political uncertainty about the default decision with a political cost that directly affects the expected payoffs.¹⁴ The political default shocks are modeled as transitory utility shocks ϵ_t^r and ϵ_t^d drawn independently each period from the same distribution such that their difference ($\epsilon_t^r - \epsilon_t^d$) is logistically distributed with mean zero and variance $\sigma_\epsilon^2 = (\pi\psi)^2/3$; ψ is a positive scaling parameter.¹⁵ To keep the notation short, in the following I denote the lifetime utilities net of their respective current period political costs with a tilde, e.g., \tilde{V}^r or \tilde{V}^d with

$$\tilde{V}^r(b_{t-1}, z_t) := V^r(b_{t-1}, z_t) - \epsilon_t^r; \quad \tilde{V}^d(z_t) := V^d(z_t) - \epsilon_t^d.$$

Despite the political costs, the government's default decision is still fundamentally driven by the economic costs and benefits of default. As we will see in the following, the benefit of default is an immediate higher consumption, as the inherited debt b_{t-1} no longer needs to be repaid. The costs of default are comprised of the cost of exclusion from the international financial market and the cost of impaired domestic financial intermediation.

The payoff of repayment is determined by the current level of productivity z_t , and the choice of new debt issuance b_t . The new debt issuance b_t solves the following constrained maximization problem, formulated in a recursive fashion

$$\begin{aligned} V^r(b_{t-1}, z_t) = & \max_{b_t, c_t} \left\{ u(c_t, h(b_t, z_t)) \right. \\ & \left. + \beta \mathbb{E}_t \max \left[\tilde{V}^r(b_t, z_{t+1}), \tilde{V}^d(z_{t+1}) \right] \right\} \quad (3.10) \\ \text{subject to} & \quad c_t + b_{t-1} = q(b_t, z_t) b_t + \tilde{y}(b_t, z_t), \end{aligned}$$

where the government's choices are constrained by the available resources of the economy.

¹⁴An alternative setup of the model is to assume that the political default costs affect the government's utility but not that of the households. This would induce a discrepancy between the government's and the households' welfare. However, it can be shown that the two setups provide identical results.

¹⁵In particular, I assume that the political costs ϵ^i are i.i.d. according to a double exponential distribution. This allows me to apply the random utility approach to the multinomial logit model. See Suppes and Luce (1965) and the reference therein. π refers to the mathematical constant

3.2. Theoretical framework

\tilde{y}_t is output net of real resource costs used in the financial intermediation

$$\tilde{y}_t = y_t - K\Psi(u_t) - \phi r_t (w_t h_t + K\Psi(u_t)). \quad (3.11)$$

Through the sovereign risk spillovers and the existence of working capital, both \tilde{y}_t and h_t , become a function of the government's new debt issuance and the productivity level.

If the government has no access to the international market, the households can only consume output net of resource costs. Let \tilde{y}^D, h^D denote labor and output net of resource costs, evaluated using (3.6) and (3.8) at $r_t = r^D$. The payoff of defaulting thus is

$$V^d(z_t) = u(\tilde{y}^D(z_t), h^D(z_t)) + \beta \mathbb{E}_t \left[\theta V^r(b_t = 0, z_{t+1}) + (1 - \theta) V^d(z_{t+1}) \right]. \quad (3.12)$$

The continuation value reflects the assumption that with probability θ the government regains access to the international financial market in the next period, with zero initial debt.¹⁶

INTERNATIONAL INVESTORS

The international investors are risk-neutral and have an opportunity cost of funds equal to the risk-free rate r . The international market is competitive, implying that investors have zero expected profits when they lend to the regional government. The price schedule for government bonds thus is

$$q_t = \frac{\mathbb{E}_t \text{prob}(b_t, z_{t+1})}{1 + r}, \quad (3.13)$$

where $\text{prob}(b_t, z_{t+1})$ is the probability with which the regional government repays its liability b_t in $t + 1$. For a j -state productivity realization, the repayment probability is

$$\text{prob}(b_t, z_j) = \text{P} \left\{ \tilde{V}^r(b_t, z_{t+1} = z_j) \geq \tilde{V}^d(z_{t+1} = z_j) \right\}. \quad (3.14)$$

3.2.2 The optimal risk sharing scheme

In the baseline model, the regional government's ability to self-insure is constrained not only by the incompleteness of the international financial market but also by its inability to commit. The resulting sovereign risk spillovers further amplify recessions and hamper the

¹⁶The political costs do not appear in the continuation value because they are i.i.d. distributed with mean zero.

3.2. Theoretical framework

government's ability to borrow in unfavorable economic times. In this section, I examine the optimal interregional risk sharing arrangement in this setup. I characterize the optimal risk sharing arrangement as an optimal contract using the promised utility approach.¹⁷ The federal planner's objective is to maximize the sum of the welfare of the small open economy and the international investors, and it observes the realization of the productivity states of the economy but not the political costs. The planner designs the contract that specifies the payment terms and the debt structure of the debtor country at each specific time and productivity state. This includes the level of official liabilities and the level of external borrowing from the international market under the conditions described above. In other words, the planner chooses when and how much is transferred/repaid and she also constrains the sovereign's borrowing on the international market.

The planner designs the contract by maximizing the present value of expected cash flows, given the utility level of the small open economy. The regional government still cannot commit and may default on its borrowing from the international investors as well as its liabilities to the planner as specified in the contract. However, to reflect the seniority of the risk sharing agreement on the federal level, I assume that the government cannot choose to default on the contract alone. In particular, if the government defaults on private external debt, it will be excluded from the international financial market (as described above) but it still participates in the risk sharing arrangement. However, if it defaults on the contract the international market also stops lending to the government. Furthermore, defaulting on the contract excludes any future possibility for the government to reenter the optimal contract again. The implicit assumption is that the planner has a stronger punishment instrument and can credibly threaten the government that it will stop providing any more emergency funds after a violation of the contract. The international investors, however, fail to coordinate to achieve such a punishment. Consequently, if the government decides to default on the contract, the economy reverts to the one described in the baseline model after default. When the government has not defaulted on the contract, the planner's optimization problem is to maximize discounted cash flows from the contract $\{p_j\}_{j=t}^{\infty}$ subject to a given level of promised utility to the government.¹⁸ The planner distinguishes between two cases: (1) the regional government has access to the international market; (2) the

¹⁷The promised utility approach has been widely used. See for example Spear and Srivastava (1987), Thomas and Worrall (1988), Ljungqvist and Sargent (2004), Aguiar and Amador (2014), DAVIS (forthcoming) for an application in the sovereign default context.

¹⁸ $p_t < 0$ implies transfers to the regional government; $p_t > 0$ repayments from the government.

3.2. Theoretical framework

regional government has no access to the international financial market.

NO ACCESS TO THE INTERNATIONAL FINANCIAL MARKET

Let us first look at the federal planner's problem when the regional government has no access to the international financial market. J denotes the contract value from the planner's perspective if the government has access to the financial market, and J^d if not. The contract has a value of zero if the government has reneged on the contract. The state variables are the productivity level z_t as well as the promised utility v_t^d . The planner's choice variables include the current period repayment/transfer p_t and the next period promised utilities. In particular, if the government regains market access in $t + 1$ and the realized productivity level is $z_{t+1} = z_j$, its promised utility is $v_{j,t+1}^{db}$. If the government remains without market access, the planner promises to deliver a utility level of $v_{j,t+1}^{dd}$ conditional on the productivity state j . Again, I use a tilde to denote the promised value net of political costs. The planner's optimization problem is

$$J^d(v_t^d, z_t) = \max_{\substack{p_t, c_t, \\ \{v_{j,t+1}^{db}\}_{j=1}^J, \\ \{v_{j,t+1}^{dd}\}_{j=1}^J}} \left\{ p_t + \frac{1}{R} \mathbb{E}_t \left[\theta \text{prob}^{db}(v_{t+1}^{db}, z_{t+1}) J(v_{t+1}^{db}, b_t = 0, z_{t+1}) \right. \right. \\ \left. \left. + (1 - \theta) \text{prob}^{dd}(v_{t+1}^{dd}, z_{t+1}) J^d(v_{t+1}^{dd}, z_{t+1}) \right] \right\} \quad (3.15)$$

$$\text{subject to } v_t^d = u(c_t, h^D(z_t)) + \beta \mathbb{E}_t \left[\theta \max \{ \tilde{v}_{t+1}^{db}, \tilde{V}^d(z_{t+1}) \} \right. \\ \left. + (1 - \theta) \max \{ \tilde{v}_{t+1}^{dd}, \tilde{V}^d(z_{t+1}) \} \right] \\ c_t = \tilde{y}^D(z_t) - p_t \quad (3.16)$$

The first constraint facing the planner is the “promise-keeping” constraint. It ensures that the small open economy indeed receives the level of lifetime utility v_t^d that was promised by the planner last period. This lifetime utility consists of the current period's utility and the continuation value of the government. This continuation value reflects the two $t + 1$ -scenarios concerning the government's access to the international financial market, as well as the government's limited commitment problem. With probability θ , the government regains market access, in which case it chooses to repay the contract obligation with probability $\text{prob}^{db}(\cdot)$. With probability $(1 - \theta)$, the government remains without access to the international financial market, in which case it honors its contract obligation with probability $\text{prob}^{dd}(\cdot)$. The second constraint reflects the resource constraint of the regional

3.2. Theoretical framework

economy: since it does not have access to the international financial market, it can only consume its output net of real resource costs minus the payment p_t .

WITH ACCESS TO THE INTERNATIONAL FINANCIAL MARKET

When the government has access to the international market, the value of the contract is a function of the promised utility v_t and the productivity level z_t , as well as the level of the inherited debt of the government b_{t-1} . Besides the current period transfer, the federal planner also chooses the current period's new issuance of debt b_t . As shown in (3.17), the contract value $J(\cdot)$ consists of the current repayment by the government p_t and a continuation value, which is itself a weighted average of possible contract values in $t + 1$. With probability $\pi(z_j | z_t)$, the productivity level is z_j in $t + 1$. Given this productivity state, the government will receive a lifetime utility $v_{j,t+1}$ if it chooses to repay the international debt and honor its contract obligation. It will have a lifetime utility $v_{j,t+1}^d$ if it repays only its contract obligation but defaults on international debt. In $t + 1$, after observing the realized productivity level and the political costs, the government makes its default decision by comparing these promised utilities including their individual political costs with its other option – defaulting on all obligations and receiving \tilde{V}^d . With probability $prob(\cdot)$ the government repays all its liabilities, with probability $prob^d(\cdot)$ it defaults only on international debt. The optimal contract is characterized by the following optimization problem

$$J(v_t, b_{t-1}, z_t) = \max_{\substack{p_t, c_t, b_t, \\ \{v_{j,t+1}\}_{j=1}^J, \\ \{v_{j,t+1}^d\}_{j=1}^J}} \left\{ p_t + \frac{1}{R} \mathbb{E}_t \left[prob(v_{t+1}, b_t, z_{t+1}) J(v_{t+1}, b_t, z_{t+1}) \right. \right. \\ \left. \left. + prob^d(v_{t+1}^d, b_t, z_{t+1}) J^d(v_{t+1}^d, z_{t+1}) \right] \right\} \quad (3.17)$$

$$\text{subject to } v_t = u(c_t, h_t) + \beta \mathbb{E}_t \left[\max \left\{ \tilde{v}_{t+1}, \tilde{v}_{t+1}^d, \tilde{V}^d(z_{t+1}) \right\} \right] \\ c_t + b_{t-1} + p_t = q_t b_t + \tilde{y}_t$$

The first constraint is again the “promise-keeping” constraint. The continuation value from the perspective of the regional government reflects the three options which it can choose from in $t + 1$: (1) repay all liabilities; (2) repay only the contract obligation; (3) default on all liabilities. The second constraint is the resource constraint of the regional economy. The bond price schedule q is defined as in (3.13) and depends on the expected probability that

3.2. Theoretical framework

debts to international investors will be repaid next period. As in the baseline model, h_t and y_t depend on the productivity state as well as the government bond prices.

The planner, by directly choosing the transfers/repayments and promised utility, can provide productivity-state-contingent transfers to the government. This enables the planner to strike a balance between insuring the regional economy against economic downturns and instilling it with an incentive not to default. Under the optimal contract, the government's obligations are tailored to the productivity level. The government is required to contribute to the risk sharing arrangement when its economy is in good shape and receives transfer when facing negative productivity shock. As a result, a surprisingly low level of productivity is no longer associated with a repayment that requires a painful cut in domestic consumption. In equilibrium, defaults can still happen for economic or political reasons. But thanks to the state contingency, defaults triggered by adverse productivity shocks are much less likely. In this way, the planner can provide better insurance and ameliorate recessions, despite the government's limited commitment.

3.2.3 The standby facility

The optimal contract described above can be implemented in a fiscal union where the government of the small open economy and the other member states agree upon ex-post interregional transfers and repayments that are contingent on the realized productivity shocks and agree to restrictions on borrowing on the international market. A simpler way to provide insurance is the provision of a standby facility – an emergency fund – with repayment obligations that do not depend on future economic outcomes. Since the European debt crisis has begun, several such emergency fund mechanisms have been set up to tackle the lack of risk sharing within the euro area (e.g., the European Stability Mechanism).¹⁹ I now turn to the analysis of such a standby facility. How does it compare to the optimal insurance scheme?

The standby facility provides a limited amount of funds $\check{b} < \bar{b}$ at a fixed interest rate $r^b \geq r$. For simplicity, I assume that if the government decides to take up the emergency fund, it uses it in full (i.e., $\check{b}_t = \bar{b}$). As a condition, it is subject to a fiscal constraint that restricts the amount of debt that it can issue on the international market.²⁰ Analogous

¹⁹Another notable standby facility that is in place as an insurance mechanism is the IMF standby facility.

²⁰The European Stability Mechanism explicitly states that its lending happens only under strict conditions and countries using it must implement reforms. Such fiscal conditionality also often accompanies the IMF bailout fund. It is furthermore worth pointing out that although the optimal contract does not explicitly

3.2. Theoretical framework

to the optimal contract, the bailout fund is more senior than the private sector debt. The government can choose to default on its liabilities toward international investors, or this *and* the emergency fund together. It cannot choose to default only on the standby facility. Entering the standby facility is associated with some political cost $\kappa \geq 0$. Staying in or exiting the facility is not associated with any political cost. So there are three features of the standby facility that potentially prevent the government from always making use of the fund: the spread between the riskfree rate and the interest rate on the emergency fund, the borrowing constraint, and the political costs. The interest rate r^b serves to ensure that the standby facility is balanced-budget, despite the limited commitment problem on the side of the regional government. Let \check{b}_{t-1} denote the level of the emergency fund that the government used in the last period $t - 1$. \check{b}_{t-1} can take two values

$$\check{b}_{t-1} = \begin{cases} 0 & \text{if the government was not using the emergency fund in } t - 1 \\ \bar{b} & \text{otherwise} \end{cases} \quad (3.18)$$

Table 3.1: Government's debt decision

	Access to int. fin. market in t	Standby facility in $t - 1$	Option payoffs
(1)	no	no	$\tilde{V}^{d, nofund}(0, z_t), \tilde{V}^{d, fund}(0, z_t) - \kappa$
(2)	no	yes	$\tilde{V}^{d, nofund}(\bar{b}, z_t), \tilde{V}^{d, fund}(\bar{b}, z_t), \tilde{V}^d(z_t)$
(3)	regain	no	$\tilde{V}^{r, nofund}(0, 0, z_t), \tilde{V}^{r, fund}(0, 0, z_t) - \kappa$
(4)	regain	yes	$\tilde{V}^{r, nofund}(0, \bar{b}, z_t), \tilde{V}^{r, fund}(0, \bar{b}, z_t), \tilde{V}^d(z_t)$
(5)	yes	no	$\tilde{V}^{r, nofund}(b_{t-1}, 0, z_t), \tilde{V}^{r, fund}(b_{t-1}, 0, z_t) - \kappa,$ $\tilde{V}^{d, nofund}(0, z_t), \tilde{V}^{d, fund}(0, z_t) - \kappa$
(6)	yes	yes	$\tilde{V}^{r, nofund}(b_{t-1}, \bar{b}, z_t), \tilde{V}^{r, fund}(b_{t-1}, \bar{b}, z_t),$ $\tilde{V}^{d, nofund}(\bar{b}, z_t), \tilde{V}^{d, fund}(\bar{b}, z_t), \tilde{V}^d(z_t)$

The timeline is similar to that in the baseline model. At the beginning of period t , after observing the realization of the productivity level, the government decides over its debt specify a similar borrowing constraint, the planner, in fact, chooses the exact level of private external debt that the government takes up.

3.2. Theoretical framework

policy and whether to use the standby facility. If the government has defaulted on the emergency fund its continuation value is V^d since it no longer has access to the standby facility. If it has not defaulted on the standby facility, its decision problem depends on whether it has access to the international financial market as well as whether it has used the standby facility in the last period. We have to distinguish between six cases, which are summarized in Table 3.1. $\tilde{V}^{d,nofund}(\check{b}_{t-1}, z_t)$ is the value function net of political cost of the regional government when it has no access to the international market and decides not to use the emergency fund, $\tilde{V}^{d,fund}(\check{b}_{t-1}, z_t)$ is the value function under the same circumstances but the government uses the emergency fund. $\tilde{V}^{r,nofund}(b_{t-1}, \check{b}_{t-1}, z_t)$ is the value function net of political cost when the government has access to the international market and is not using the emergency fund, $\tilde{V}^{r,fund}(b_{t-1}, \check{b}_{t-1}, z_t)$ is the corresponding value function if the government uses the emergency fund.

(1) If the government has no access to the financial market and was not using the standby facility, it can choose between not using the emergency fund or start using it.²¹ (2) If the government has no access to the financial market and was already using the standby facility last period, it can choose between exiting the standby facility, rolling over the fund or defaulting on the standby facility. (3) If the government has just regained access to the financial market and was not using the standby facility, it chooses between whether or not to start using the fund. (4) If the government has just regained access to the financial market and was using the standby facility, it can also choose to default on the bailout fund. (5) If the government has access to the financial market and it has inherited international liability b_{t-1} but was not using the standby facility, it chooses between not using the fund, starting to use the fund, defaulting on the international debt but not using the fund, as well as defaulting and starting to use the fund. Finally, (6) If the government has access to the financial market and has inherited international liability b_{t-1} but has to pay back last period's standby facility, it chooses between exiting the standby facility, rolling over the fund, defaulting on the international debt, payback and exiting the emergency fund, defaulting on the international debt and rolling over the standby facility or defaulting on all liabilities. The four value functions are determined by the following maximization problem of the government

²¹As the government has zero external obligation, in this case, default is not a relevant option.

3.2. Theoretical framework

$$V^{d,nofund}(z_t) = u(c_t, h_t^D) + \beta \mathbb{E}_t \left\{ \theta \max \left[\tilde{V}^{r,nofund}(0, 0, z_{t+1}), \tilde{V}^{r,fund}(0, 0, z_{t+1}) - \kappa \right] \right. \\ \left. + (1 - \theta) \max \left[\tilde{V}^{d,fund}(0, z_{t+1}) - \kappa, \tilde{V}^{d,nofund}(0, z_{t+1}) \right] \right\}$$

$$\text{and } c_t + (1 + r^b)\check{b}_{t-1} = \tilde{y}_t^D$$

$$V^{d,fund}(\check{b}_{t-1}, z_t) = u(c_t, h_t^D) + \beta \mathbb{E}_t \left\{ \theta \max \left[\tilde{V}^{r,nofund}(0, \bar{b}, z_{t+1}), \tilde{V}^{r,fund}(0, \bar{b}, z_{t+1}), \right. \right. \\ \left. \left. \tilde{V}^d(z_{t+1}) \right] + (1 - \theta) \max \left[\tilde{V}^{d,nofund}(\bar{b}, z_{t+1}), \tilde{V}^{d,fund}(\bar{b}, z_{t+1}), \tilde{V}^d(z_{t+1}) \right] \right\}$$

$$\text{and } c_t + (1 + r^b)\check{b}_{t-1} = \tilde{y}_t^D + \bar{b}$$

$$V^{r,fund}(b_{t-1}, \check{b}_{t-1}, z_t) = \max_{b_t, c_t} u(c_t, h(b_t, z_t)) + \beta \mathbb{E}_t \max \left\{ \tilde{V}^{r,nofund}(b_t, \bar{b}, z_{t+1}), \right. \\ \left. \tilde{V}^{r,fund}(b_t, \bar{b}, z_{t+1}), \tilde{V}^{d,nofund}(\bar{b}, z_{t+1}), \tilde{V}^{d,fund}(\bar{b}, z_{t+1}), \tilde{V}^d(z_{t+1}) \right\}$$

$$\text{subject to } c_t + b_{t-1} + (1 + r^b)\bar{b} = \tilde{y}(b_t, z_t) + q(b_t, z_t) b_t + \check{b}_{t-1}$$

$$\text{and } b_t \leq b_{t-1}$$

$$V^{r,nofund}(b_{t-1}, \check{b}_{t-1}, z_t) = \max_{b_t, c_t} u(c_t, h(b_t, z_t)) + \beta \mathbb{E}_t \max \left\{ \tilde{V}^{r,nofund}(b_t, 0, z_{t+1}), \right. \\ \left. \tilde{V}^{r,fund}(b_t, 0, z_{t+1}) - \kappa, \tilde{V}^{d,nofund}(0, z_{t+1}), \tilde{V}^{d,fund}(0, z_{t+1}) - \kappa \right\}$$

$$\text{subject to } c_t + b_{t-1} + (1 + r^b)\bar{b} = \tilde{y}(b_t, z_t) + q(b_t, z_t) b_t$$

The bond price schedule is again defined analogously to (3.13) and the next period repayment probability is the sum of the probability that the government exits the fund and repays the debt and that of the government rolling over the fund and repaying the international debt.

3.3 Quantitative analysis

3.3.1 Calibration

I calibrate the quarterly model to Greece starting in 2001Q1 when Greece joined the euro area and ending in 2012Q1 just before the Greek default.²² Some of the parameter values are chosen directly, in accordance with the sovereign debt or RBC literature; others are estimated or calibrated to reflect data moments. The calibration is reported in Table 3.2.

The intertemporal elasticity of substitution is set to 1/2 and the Frisch elasticity of labor supply to 1/2.2 as in Mendoza and Yue (2012). The curvature of the production function γ is set to 2/3. All these values are consistent with the RBC literature. The world riskfree interest rate equals the average real 10-year government bond yield of 1.02 (1.005 at quarterly frequency). As the capital stock in the model reflects the one used in the production process, I calibrate K to the sample average Greek non-residential capital to GDP ratio of 120%.²³ The productivity level is chosen so that the model non-stochastic steady state output is normalized to one. I assume that after default the government regains access to the international financial market with a quarterly probability of $\theta = 0.125$. This implies an average expected duration of exclusion from the financial market of 2 years, which is consistent with the empirical findings in Gelos, Sahay and Sandleris (2011). Greece adheres to this pattern in that it issued government bonds on the international markets in 2014 after defaulting in 2012.

ϕ measures the fraction of working capital that has to be paid in advance of sales. The parameter is set to target the average ratio of Greek short-term bank loans to domestic non-financial corporations to GDP (18%).²⁴ The elasticity of capacity utilization costs concerning the level of utilization ξ , together with the Frisch elasticity of labor, pins down the degree to which the costs of financial intermediation affect output. I calibrate this parameter based on the finding in Romer and Romer (2004) that in the U.S. a one percentage increase in the nominal interest rate leads to a four percentage decrease in industrial output after two years. The cost parameter δ is calibrated to target an average

²²See Zettelmeyer, Trebesch and Gulati (2013) for a detailed analyze of the Greek debt restructuring.

²³The ratio is calculated based on the capital stock data from Kamps (2006) and the seasonally adjusted quarterly Greek nominal GDP from the OECD.

²⁴The data on short-term bank loans are from the Bank of Greece. Since this series starts in 2002Q2, the average is calculated for the period 2002Q2 to 2012Q1. The resulting value of ϕ is rather high when compared to Mendoza (2010) and Mendoza and Yue (2012). This reflects the high volume of short-term loans in the Greek economy. This is also reflected in the M1 to GDP ratios.

3.3. Quantitative analysis

capacity utilization of 75%. Ψ generates an annual depreciation of 8%. The parameters χ and α measure the magnitude of the sovereign risk spillover into private sector rates: α pins down how much the private sector financing costs increase when the sovereign bond price drops by one percent, while χ determines the mean level of the private sector interest rate. These parameters are calibrated to match the empirical relationship between the Greek sovereign bond spread and the lending interest rate spread of Greek short-term bank loans of domestic banks to non-financial corporations. The financial intermediation cost r^D is calibrated to match the same bank lending rate spread in 2012Q2, the quarter when the Greek government defaulted. Regarding the exogenous productivity process, I assume that it follows an AR(1) process

$$\log(z_t) = (1 - \rho_z) \log(z) + \rho_z \log(z_{t-1}) + \epsilon_{z,t}, \quad \text{with } \epsilon_{z,t} \stackrel{iid}{\sim} N(0, \sigma_z^2)$$

which is approximated by a Markov process following Tauchen (1986). ρ_z and σ_z are calibrated in accordance with King and Rebelo (1999), who estimate the productivity process in the U.S. using a model with indivisible labor and variable capacity utilization.

The remaining two parameters, the time discount factor β and the scale parameter of the distribution of the political default costs ψ are calibrated so that the model generates statistics that match the average Greek government bond spread of 2.67% and its standard deviation of 5.08% as observed in the data.²⁵ The model is solved numerically by iteratively finding the nonlinear policy functions that satisfy the first order conditions as well as other equilibrium conditions in each of the setups. The policy functions are approximated using 100 grid points with linear interpolation between them on the dimension of the bond holding (or promised utility) and 13 grid points on the dimension of productivity states.

²⁵The Greek government bond spread is calculated as the difference between the yields on 10-year Greek government bonds and that of the 10-year German government bonds. Both data series are available from the OECD.

3.3. Quantitative analysis

Table 3.2: Calibration

Baseline model parameters		Value	Targeted statistics
Intertemporal elasticity of substitution	$1/\sigma$	1/2	standard RBC values
Frisch elasticity of labor supply	v	1/2.2	Frisch wage elasticity (2.2) (Mendoza and Yue, 2012)
Labor share in production	γ	2/3	standard RBC values
Riskfree interest rate	$1 + r$	1.005	average 10Y German government bond yields
Capital stock	K	4.8	Greek private nonresidential capital/GDP ratio 1.2
Reentry probability	θ	0.125	average length of market exclusion after default of 2 years (Gelos et al. (2011))
Working capital parameter	ϕ	0.95	Greek short term bank loan to domestic nonfinancial corporations to GDP 18% (02'Q2-12'Q2)
Utilization cost parameter	ξ	-0.316	1% increase in r associated with 4% drop in output (Romer and Romer (2004))
Utilization cost parameter	Ψ	-0.001	annual depreciation 8% at avg. capacity utilization
Utilization cost parameter	δ	0.017	average Greek industry capacity utilization 75%
Risk spillover parameter	α	0.18	relation of the ST lending rate spread of bank loans to domestic non-fin. corporations and the sov. spread
Risk spillover parameter	χ	1.005	
Intermediation costs in default	r_d	0.019	Greek ST bank lending rate spread of bank loans to domestic non-financial corporations in 12Q2 600 bps
Mean productivity level	z	0.789	average output normalized to 1
Persistence prod. shock	ρ_z	0.99	King and Rebelo (1999)
Sd. prod. shock	σ_z	0.001	King and Rebelo (1999)
Targets from data			
Time discount factor	β	0.962	average Greek govt bond spread 2.67%
Scale parameter distribution of political default costs ϵ	ψ	0.06	standard deviation of Greek gov. bond spread 5.08%

3.3.2 Quantitative performance of the baseline model

In this section, I examine the model's quantitative performance. First, I compare the business cycle statistics generated by the baseline model with the data, then I study the ability of the model to match macroeconomic dynamics around default events. Table 3.3 shows the data statistics (columns (I)) and the baseline model statistics (columns (II)). The model moments are (sample) averages calculated by simulating the economy 5,000 times

3.3. Quantitative analysis

using productivity sequences drawn from the productivity distribution. To be consistent with the Greek pre-default sample, I only use the 45 observations prior to default events in each simulation to calculate mean statistics.²⁶ Considering the targeted statistics, the baseline model generates a 2.99% government bond spread, close to the 2.67% spread observable in the data. The model standard deviation of the government bond spread is 4.36%, slightly below the volatility observed in the data for the sample period 5.08%.

In the table, I also report data and model statistics that are not targeted in the calibration but that are often reported in the sovereign default literature. The external debt data are from the Bank of Greece, and it consists of debt securities held by foreigners.²⁷ The GDP and trade balance, as well as the 'hours worked' data are from the OECD. The data for the capacity utilization are also from OECD and based on the Business Tendency Survey covering the Greek manufacturing sector. The debt-to-output ratio generated by the model is 4.58%. As in other sovereign default models with short-term debt, the model has difficulty to generate an external-debt-to-output ratio as high as that observed in Greece. However, as the model features only short-term debt, it would exaggerate the short-term refinancing need if we compare the model to the total external sovereign debt-to-output ratio. Over the sample period, the Greek external-debt-to-output ratio averaged at 51.6% and on average 9.9% of the total outstanding external debt is due within the next year.²⁸ This implies a Greek average short-term debt-to-GDP ratio of 5.11%, comparable to the debt-to-output ratio in the model. On the production side, the model generates volatility in $\log(\text{output})$ that is close to that in the data but understates the persistence. The model can reasonably well capture the correlations between output and the government bond spread, the trade balance, labor, as well as the level of capacity utilization. Furthermore, the model generates correlations between government bond spread and the trade balance, labor, as well as the level of capacity utilization closed to the data.

Evidently, the model does a good job of predicting the cyclical co-movements. It is also able to match the dynamics of the main variables around default events. As the main benefits of the risk sharing arrangement come from the avoidance of severe recessions, I

²⁶45 quarters corresponds to the length of the Greek sample from 2001Q1 to 2012Q1. Time series from the simulation are processed in the same way as the empirical time series. To limit the results' dependence on initial conditions, I discarded the first 30 observations.

²⁷Before the default in 2012Q2, the majority of Greek external debt was in the form of debt securities. This changes after the default and the second bailout package, as the bailout program counts as a loan.

²⁸This is based on data on Greece's central government debt (maturing within one year) from the Bank of International Settlement.

3.3. Quantitative analysis

Table 3.3: Statistical moments: model vs. data

	(I)	(II)
Targeted statistics	Data	Baseline model
Govt. bond spread (%)	2.67	2.99
Standard deviation of govt. bond spread (%)	5.08	4.36
Non-targeted statistics		
Short term debt to output ratio (%)	5.11	4.58
Persistence log(output)	0.88	0.71
Standard deviation of log(output)	5.86	5.74
Correlation with log output		
govt bond spread	- 0.92	- 0.57
trade balance	- 0.76	- 0.44
labor	0.68	0.72
capacity utilization	0.74	0.71
Correlation with govt bond spread		
trade balance	0.71	0.52
labor	- 0.56	- 0.52
capacity utilization	- 0.77	- 0.51

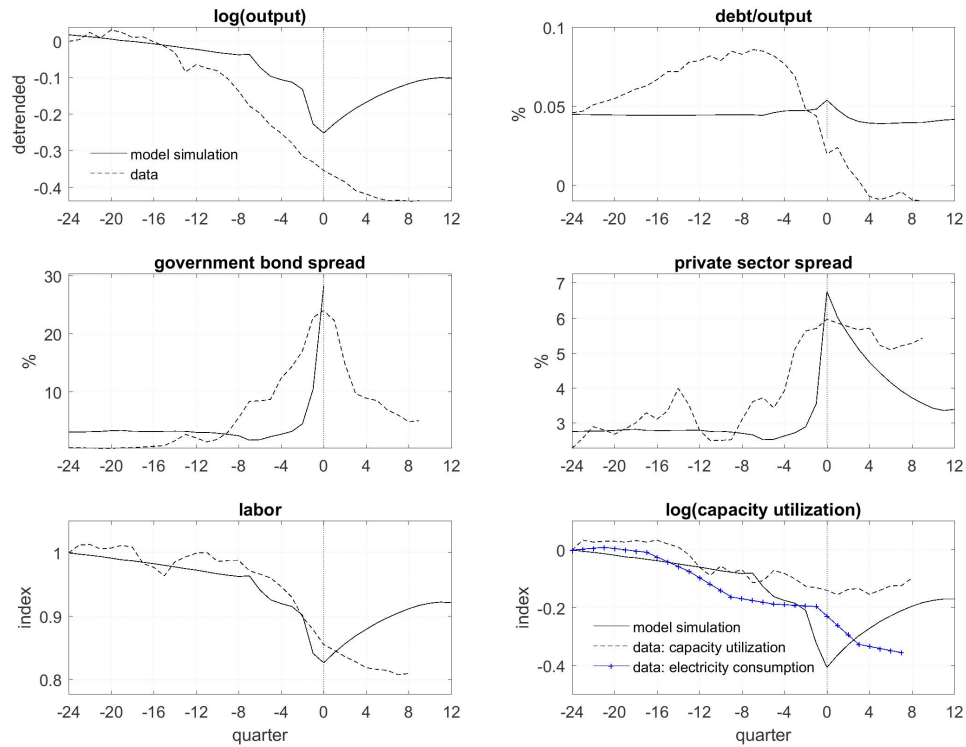
Note: All data statistics are calculated for the period from 2001Q1 to 2010Q1 (45 quarters), except for output. The log(output) statistics are calculated on the basis of the linearly detrended log real GDP series for Greece from 1980Q1 - 2010Q1. Trade balance is defined as net export as percentage of GDP. All model statistics are (average) statistics based on the 45 pre-default observations obtained from 5,000 stochastic simulations (see text).

check whether the model generates recessions of the magnitude observed in Greece during its debt crisis. Figure 3.1 shows the model's average path around default events and depicts the simulated time series of the linearly detrended logarithm of output, debt-to-output ratio, annualized government bond spreads, domestic costs of financial intermediation, labor, and capacity utilization. The average path is calculated as the sample mean of 5,000 simulations underlying the previous model statistics. The figure plots the event window covering 24 quarters before and 12 quarters after a default. For comparison, the figure also shows the Greek data around the 2012Q2 default, from 2007Q2 to 2014Q4 (dashed lines).

The model output and labor show a strong resemblance to the Greek data before the 2012 default. Noteworthy, the model features gradual drops in output and labor before

3.3. Quantitative analysis

Figure 3.1: Model dynamics around default events



Note: Model simulations are time series averages of stochastic simulations, in which a default was observed. The horizontal axis shows the quarters before (-) and after (+) a default. Log(output) is linearly detrended. The government bond spread and private sector spreads are annualized. Log(capacity utilization) and labor are indices with $t = -24$ normalized to zero or one. Data of electricity consumption are linearly interpolated based on annual data available at the World Bank.

default events as observed in the data.²⁹ The model is also able to generate a strong increase in the government bond spread and, by construction, a jump in the private sector cost of financial intermediation. However, the matching of the debt-to-output ratio is less satisfactory. The model features only a small accumulation of debt and has a debt-to-output ratio that peaks around default events. In Greece, the debt ratio had a much larger increase before 2010 and the ratio started to decline in 2010Q3, just after Greece received its first

²⁹This also poses a strong resemblance to the data of defaults also in other countries (see for example Mendoza and Yue, 2012).

3.3. Quantitative analysis

bailout package.

Finally, the model generates a severe drop in capacity utilization. This drop is much larger than the drop in the capacity utilization time series based on the Business Tendency Survey conducted for the manufacturing sector. However, the model matches better an alternative proxy for capital utilization that is commonly used – electricity consumption.³⁰ The electricity utilization series suggest that economy-wide capacity utilization in Greece during the crisis has indeed declined substantially. The discrepancy between the manufacturing business survey data and the electricity utilization data most likely reflects sectoral performance differences within the Greek economy during the crisis. The Greek manufacturing sector was only one among the sectors hit hard by the debt crisis.³¹ I deem the electricity utilization data the more relevant series here, because it better reflects economy-wide capacity utilization.³²

3.3.3 Impact of the optimal risk sharing scheme and the standby facility

Equipped with the calibrated model I now proceed to analyze the welfare effects of the two different interregional risk sharing arrangements: (1) the optimal transfer scheme and (2) the standby facility. In particular, I analyze whether such forms of international insurance are welfare improving, and if so, by how much the optimal insurance scheme is superior to the simpler and politically more feasible standby facility.

Table 3.4 compares the business cycle statistics of the baseline model without international insurance with the business cycle statistics of the models with the two international insurance schemes. The statistics are calculated as sample averages of 100,000 stochastic simulations, each with 45 observations, which may include periods where the government does not have access to the international market.³³ Including the default states allows the statistics to reflect the role of the risk sharing arrangement on default frequency. It is

³⁰Examples of other papers using electricity consumption as a proxy for capacity utilization are King and Rebelo (1999) and Gertler et al. (2007) and the references therein. The data is available at the World Bank at an annual frequency.

³¹Between 2007 and 2014, Greece has also seen a large drop in real gross value added in construction, sales, transports, and services sectors, which together account for more than 50% of the economy-wide drop in gross value added.

³²Both the manufacturing capacity utilization and the (detrended) electricity consumption in Greece was stable until the onset of the global crisis in 2007, after which electricity consumption has shown a larger decrease than the manufacturing capacity utilization.

³³The underlying productivity sequences are identical for each of the designs. To limit the results' dependence on initial conditions, I discarded the first 30 observations.

3.3. Quantitative analysis

assumed that the insurance schemes are introduced in the first period of the simulation ($t = 0$). In this period the government still has access to the international financial market. While the starting point for the standby facility is thus defined, the initial conditions of the optimal contract are not. The optimal contract as characterized by $J(v_0; b_{-1}, z_0)$ traces out the Pareto frontier for the small open economy and the rest of the currency union. However, it is silent about the initial value v_0 .³⁴ Some constraints need to be satisfied to ensure that all parties are indeed willing to enter into the optimal risk sharing arrangement: (1) the regional government should not be worse off, in welfare terms, under the contract than in the baseline setup without the contract, i.e. $v_0 \geq V^r(b_{-1}, z_t)$. (2) The optimal contract is not associated with net transfers, i.e. the contract has an initial net present value that at least breaks even $J(v_0, b_{-1}, z_t) \geq 0$. This means that the risk sharing scheme, in expectation, constitutes no extra burden to the taxpayers in other member states of the currency union. Within the euro area context, this is a feature of international insurance commonly demanded by creditor countries. As a shortcut to the explicit modeling of the complex and multidimensional bargaining process between member states, I set the initial conditions of the contract in such a way that it exactly breaks even, i.e. $J = 0$.³⁵ Analogously, the interest rate on the standby facility r^b is set in such a way that on average the discounted net cash flow to the standby facility equals zero. In other words, despite the possibility of the regional government defaulting on the standby facility, in expectation, this does not represent a net transfer from other member states.

The baseline model (column I) is compared to the setup with the optimal insurance scheme featuring productivity-state-contingent transfers and repayments (column II). The level of output under the optimal insurance scheme exceeds the level of output in the baseline model without international insurance by 1.5%. Also, the standard deviation of output is reduced from 7.04% to 5.79% – an 18% decrease. Relatedly, the default probability under the optimal insurance is substantially lower when the optimal international insurance scheme is in place. As the optimal insurance scheme reduces default probability, it weakens the asymmetric amplification of negative shocks through the sovereign risk spillover channel.

³⁴Per assumption the government repays the maturing debt b_{-1} to the international private creditors at the time of the introduction of the insurance scheme.

³⁵Results for the case in which $v_0^d = V^r(b_{-1}, z_t)$ are very similar. This is because, as is typical in the context of optimal contracts with one-sided no-commitment, promised utility converges over time. The intuition has been described as *amnesia* in the literature: because the government can always walk away from the contract, whenever it has a good outside option, the planner also has to offer an attractive promised utility to prevent default, leading to the convergence of promised utility over time. See for example Kocherlakota (1996) and Aguiar and Amador (2014).

3.3. Quantitative analysis

As a result, the average output during recessions increases from 0.92 to 0.96 by about 4%. Here, I define a recession as observations with a productivity level below trend. Furthermore, the level of consumption is higher under optimal insurance, and its standard deviation is lower. All in all, the optimal insurance scheme improves households' welfare over the non-insurance baseline by 0.96% in terms of certainty equivalent consumption.³⁶

Table 3.4: Statistical moment: baseline model vs. insurance schemes

Average statistics	(I)	(II)	(III)	(IV)	(V)
	Baseline	Optimal transfer	low κ	high κ	high \bar{b}
Output	1.02	1.04	1.04	1.04	1.04
Standard deviation of output (%)	7.04	5.80	5.86	6.48	5.83
Average output in recessions	0.92	0.96	0.96	0.96	0.96
Consumption	0.92	0.93	0.93	0.93	0.93
Standard deviation of consumption (%)	6.84	4.67	5.75	6.52	5.71
Probability of default (% per year)	2.06	0.02	0.03	1.88	0.03
Time in bailout (%)	-	-	64.01	2.75	62.62
Welfare improvement (%)		0.96	0.74	0.64	0.51

All statistics calculated as average statistics of 100,000 stochastic simulation. Each simulation episode has 45 observations. Average output with productivity below trend are the sample average of output observations where the productivity level z is below its mean. Welfare improvements under the interregional transfers are expressed as percentage changes in the certainty equivalent consumption compared to the baseline model, where the labor level is assumed to be the baseline average level. Low κ : $\kappa = 0.2, \bar{b} = 50\%$ of average debt. High κ : $\kappa = 0.6, \bar{b} = 50\%$ of average debt. high \bar{b} : $\kappa = 0.2, \bar{b} = 70\%$ of average debt.

How does the optimal insurance scheme compare to the politically more feasible standby facility? In general, the standby facility achieves welfare gains that come surprisingly close to the welfare gains of the optimal insurance scheme (see columns III to V). The impact of the standby facility depends on the several parameters that characterize its design, including

³⁶I compare the certainty equivalent consumption while assuming the labor is kept at its average level in the baseline model. The certainty equivalent consumption level \bar{c} is one that solves $V = ((\bar{c} - \bar{h}^{1+v}/(1 + v))^{1-\sigma} - 1)/(1 - \sigma)$, where \bar{h} is set to the baseline average. The welfare effect is calculated by comparing the average value function value of the households of the regional economy (e.g. V^r) and the political costs does not affect this comparison because they average at zero.

3.3. Quantitative analysis

the amount of funds available (\bar{b}), and the political costs (κ). To gauge how these features affect the role of the standby facility, I examine three different cases. Columns (III) and (IV) display the results for the scenarios when the amount of funds available is 50% of the average debt level in the baseline model. This is comparable to the size of the first Greek bailout in 2010. The low κ scenario assumes a low political cost of bailout fund access, while the high κ scenario assumes a high political cost. Column (V) shows the results for the case when the amount of funds is higher at 75% of the average debt level and the political cost of starting to use the standby facility is low. As expected, the high and low political cost scenarios differ in the frequency that the government makes use of the standby facility. In the two scenarios with a lower political cost “low κ ”, the government is using the facility in more than 60% of the observations.³⁷ A higher political cost – “high κ ” – reduces this to only about 3% of all observations. Despite the different amount of funds available under the standby facility, and the different frequency that the regional government makes use of it, the impact of the standby facilities on output and consumption is similar, and all of them are associated with sizable welfare improvements.

The benefit of international risk sharing comes in two dimensions. First, it helps to smooth consumption – the traditional channel of insurance. More importantly, it reduces the asymmetric impact of productivity shocks and increases the average output in two related ways. It reduces the frequency of defaults and in doing so avoids the economic costs associated with default. Furthermore, also in nondefault states, the risk sharing arrangement reduces the role of sovereign risk spillovers in amplifying negative productivity shocks and thus helps to avoid large recessions. The latter effect is responsible for the major part of the welfare improvement. The standby facility, which is redundant except when the economy is facing large negative shocks, has a much more limited capacity to smooth consumption compared to the optimal risk sharing scheme. Nevertheless, its welfare impact is comparable to that of the optimal scheme, as it is capable of reducing the frequency of severe recessions and thus increasing the overall output level. Even in the case when the regional government only rarely uses the emergency fund due to high political costs, the standby facility is capable of delivering a welfare benefit of 0.64%.

³⁷This also implies that the fiscal constraint is not very effective in reducing the government’s incentive to make use of the facility.

3.4 Conclusion

This paper has examined interregional risk sharing arrangements in a currency union whose member states are afflicted with sovereign default risk that spills over into private sector financing costs. This spillover effect amplifies the recessionary impetus of negative shocks to the economy precisely when sovereign risk spreads are high and it is costly for the local government to access international financial markets. In such an environment international insurance can have a sizable and positive welfare effect because it counteracts the asymmetric impact of shocks on sovereign default risks and thereby lifts the average level of output.

Importantly, I show that a large part of the positive welfare effects of the optimal risk sharing scheme can be obtained through a simple standby facility. Although it is redundant except when the economy is facing large negative shocks and thus its capacity to smooth consumption is limited, the standby facility is still capable of reducing the frequency of severe recessions and thereby increasing the overall output level. The optimal insurance scheme allows for some extra consumption smoothing on top of that. However, the welfare benefits due to the extra consumption smoothing are relatively small compared to the welfare benefits that derive from lowering the asymmetric risk of severe recessions. The finding that a simple emergency fund can reap most of the benefits of the optimal insurance scheme is of practical relevance because whenever international insurance schemes are discussed between sovereign nation states the willingness to part with fiscal autonomy is often severely limited.

4

Sovereign Risk Spillover and Monetary Policy in a Currency Union

4.1 Introduction

The euro area debt crisis was marked by a change of dynamics. Before 2010, movements in bank interest rates were synchronized across the currency union; since 2010 asymmetric sovereign risk has gained the determinant role in driving regional interest rates. As worries about government solvency intensified, sovereigns in the periphery faced much higher financing costs than those in the core region. The increased sovereign default risk in the periphery resulted in significant stress on local banks that had invested in their government debts. This, in turn, led to an increase in the regional bank lending rates to the private sector as well as diverging development in private financing conditions from the union's perspective.¹

It is particularly interesting against the backdrop of the euro area debt crisis to study the impact of sovereign risk spillover on monetary policy. The comovement between sovereign and private borrowing rates distorts the monetary policy transmission in the periphery but to a lesser extent in the core region. As part of a currency union, this regional dispersion cannot be addressed by country-specific monetary policy but instead adds to the challenge facing the single monetary authority, the European Central Bank (ECB).² Even if spreads on public debt have subdued, the persistent high debt level in parts of the euro area implies that sovereign default risk stays relevant.

What consequences does the linkage between sovereign risk and private sector financing

¹See, for example, (Committee on the Global Financial System, 2011).

²Mario Draghi, President of the ECB, has commented on 15 November 2012 that the sovereign crisis “[...] has made difficult the transmission of impulses coming from an accommodative monetary policy through adjustments in interest rates on loans to households and firms by banks. [...] The fragmentation of the single financial market has led to a fragmentation of the single monetary policy.”

4.1. Introduction

costs have for the effects of economic shocks? And what impact does the sovereign risk spillover have for optimal monetary policy in a currency union? This paper aims to answer the two questions using a currency union model featuring sovereign risk spillover to private sector financing costs.

The theoretical framework is an extension of the two-region New-Keynesian (NK) model developed in Corsetti, Kuester, Meier and Müller (2014). In the model, households' borrowings and deposits are channeled through financial intermediaries. Due to financial frictions, private sector borrowing costs exceed the deposit interest rate – the risk-free rate – by a positive spread. On the government side, borrowings can be defaulted on, and this default risk raises sovereign risk premia over the risk-free rate. The higher the real indebtedness of the government, the more probable a sovereign default becomes. Sovereign default risk further affects private sector financing conditions: an increase in a region's sovereign risk premia is associated with an increase in the regional private sector borrowing spreads. This increase in private sector borrowing costs exerts downward pressure on inflation and output. As a result, the fiscal strength of the regional government affects local economic outcomes, which in turn influences the government's tax revenues, creating a feedback loop between macroeconomic situation, sovereign default probability, and private sector financing condition.

The sovereign risk spillover distorts shock transmissions through the working of this feedback loop. The extent of distortion, in particular, depends on shocks' effect on the sovereign default probability. This has three dimensions. First, shocks that increase a regional government's real indebtedness, for example by decreasing output (thus tax revenues) and inflation, now exercise an additional downward pressure on output and inflation through the feedback loop. Second, the monetary policy and the maturity of government debts matter. As a shock hits the economy, it triggers a change in the risk-free policy rate; the magnitude of changes depends on the reaction function of the monetary authority. Because the government financing costs move with the risk-free rate, a larger reduction of risk-free rate generates a larger reduction of the government indebtedness. This, however, also interacts with the maturity structure of the government debt. While government debts are short term, current changes in interest rate can have a substantial effect on the government debt level. The impact fades away, as the maturity of government debt increases. Finally, how much an increase in indebtedness raises default probability hinges on the initial level of the government indebtedness. This is because sovereign default probability becomes more sensitive to changes in debt level at a higher level of indebtedness,

4.1. Introduction

an empirical fact that has been widely documented.³

To quantify the effect of sovereign risk spillover on shock transmissions, I calibrate the model to the euro area with an average residual maturity of around six years (Lojsch, Rodriguez-Vives and Slavik, 2011). If the union-wide central bank follows a simple Taylor rule, the impact of the sovereign risk spillover is negligible for most of the shocks. Exceptions are shocks that directly affect government indebtedness or sovereign debt risk premia – these shocks would not have had any effect if not due to the sovereign risk channel. Assuming short-term debt would, however, exaggerates the impact of the spillover on the transmission of all shocks.

As already pointed out in Cúrdia and Woodford (2016), a spread between interest rates available to borrowers and savers can have welfare consequences. As mentioned before, the existence of spreads can alter the shock transmissions, leading output and inflation further away from its efficient level. Moreover, movements in spread also prevent the relative consumption of borrowers and savers from reaching its efficient level, leading to a distributional efficiency. Finally, in a two-region currency union with asymmetrical spreads, from the difference between regions emerges an additional dimension of cross-region distributional efficiency that cannot be addressed with a monetary policy tailored to each of the regions. As a result, the theoretical welfare-loss function of the currency union now comprises of four gaps – output, inflation, average union-wide private sector spreads, and the relative spread between regions – each measured as the (squared) distance to their respective efficient levels.

Optimal monetary policy needs to strike the right balance between minimizing these gaps. To provide analytical insights into how optimal monetary policy is affected by the sovereign risk spillover, I derive an optimal target criterion for a simplified version of the model. The target criterion shows that when facing positive spreads, the central bank should tolerate a higher level of output and inflation than absent the sovereign risk to reduce sovereign indebtedness and the distributional inefficiency. Moreover, in the currency union setup, the central bank should act more expansionary if the region experiencing high spreads is also one that has a higher government debt level. This helps to counteract the cross-region distributional inefficiency.

But what is the quantitative implication for optimal monetary policy? In a numerical

³See, among others, Alesina, De Broeck, Prati and Tabellini (1992) and Corsetti, Kuester, Meier and Müller (2013) for empirical evidence on the nonlinearity between sovereign risk premia and government indebtedness.

4.1. Introduction

exercise under the euro area calibration, I show that optimal monetary policy can be well-approximated by the NK-target criterion that describes the optimal linear relation between inflation and output gap in the standard NK model without credit spreads. A target criterion augmented with reactions to private sector spreads can bring the economy closer to the optimum. But, room for improvement is limited compared to the standard NK-target criterion.

If government debts were short-term, however, optimal monetary policy requires a much larger initial reaction to shocks than the (augmented-) target criterion prescribes. With short-term debts, the current changes in interest rate can have a large impact on the sovereign debt level. It is thus desirable to tolerate an initial larger output gap and inflation, for the sake of a large level effect on debt, the benefit from which persists into the future. With an average maturity of six years, as it is in the euro area, the simple target criterion continues to provide a good approximation of optimal policy.

This result is very similar to the findings of Cúrdia and Woodford (2016). In a closed economy where private sector spreads are driven by private sector indebtedness, they also find that the simple target criterion still provides a fairly good approximation to optimal policy. Thus they conclude, it is not necessary to adjust the target criterion according to the extent of credit frictions.⁴ My finding complements to Cúrdia and Woodford (2016) in two folds. First, irrespective of the drivers of the spreads, be it private or public sector indebtedness, the simple target criterion continues to be desirable. Second, this continues to be the case even when spreads are asymmetric between regions. The central bank, when pursuing this flexible targeting, should however take into account the effects of credit frictions and sovereign risk spillovers on the shock transmissions, as these affect the path of output and inflation.

The findings from this paper also highlight the capacity of interest rate policy to stabilize sovereign risk and its effect on the economy. Under plausible calibration, sovereign risk spillover has a limited macroeconomic effect as long as interest rate can adjust. The situation when the policy rate is constrained at the zero lower bound, which is the case in the euro area since 2012, can pose a larger challenge. As the sovereign risk premia can no longer be reined in with expansionary monetary policy, the sovereign risk spillover can contribute to the amplification of recessionary shocks. In fact, in a closed economy setup, Corsetti

⁴Cúrdia and Woodford (2010) use the same theoretical framework and show that while an adjustment for credit spreads improves upon the Taylor rule, the extent of adjustment varies on the source of exogenous disturbances.

4.1. Introduction

et al. (2013) find that, with the policy rate at zero, sovereign risk spillover exacerbates indeterminacy problem and affects macroeconomic stability. In another paper, Corsetti et al. (2014) show that in a currency union, sovereign risk in one region combined with strongly procyclical fiscal policy at the aggregate level exacerbates the risk of belief-driven deflationary downturns.

Besides the papers just mentioned, this paper is related to the growing literature that examines the sovereign-private sector linkage. On the empirical side, for example, evidence for the spillover is presented by Neri (2013), and International Monetary Fund (2013).⁵ On the theoretical front, Bocola (2016) provides a microfoundation of sovereign risk spillovers. He points out that not only do banks with exposure to government debts suffer losses when the bond price drops; increasing sovereign default risk also generates a precautionary motive for the banks to deleverage.

This paper also builds on the literature that studies monetary policy in an environment with credit spreads, including Cúrdia and Woodford (2016, 2010), Goodfriend and McCallum (2007), as well as De Fiore and Tristani (2011). Bhattarai, Lee and Park (2015) extend the Cúrdia and Woodford (2016) analysis to a currency union setup. They find that optimal monetary policy should aggressively decrease the policy rate in response to a financial shock to reduce aggregate and distributional inefficiency.

This paper complements their contribution in two aspects. First, this paper focuses on the spillover from sovereign default risk to private sector spreads. As the source of spread variations – private or public sector debt – have different implication for shock transmissions, given the prominent role of sovereign risk in the euro area debt crisis, it is of interest to also examine how spreads driven by the public sector influence monetary policy. Second, while the three papers all feature one-period debt, the current analysis highlights the importance of the debt maturity structure in shaping how financial frictions affect shock transmissions and monetary policy.

The remaining paper is structured as follows: Section 2 describes the model framework; Section 3 investigates the impact of sovereign risk spillover on shock transmissions, followed by an analysis of optimal monetary policy in Section 4. Section 5 concludes.

⁵See also Lane (2012) for a description on the evolution of the European debt crisis and the interaction between the sovereign debt crisis and the banking crisis.

4.2 The model framework

The theoretical framework builds on the currency union model in Corsetti et al. (2014). It features two regions – Home and Foreign. There are households, firms and a local government in each of the region, and a single central bank at the union level.

In the following, I will shortly outline the model and thereby focus mainly on the Home region. The economy in the Foreign region is analogous. Foreign variables are distinguished from Home by an asterisk, and union-wide variables are indexed by a bar. Unless noted otherwise, variables are expressed in per capita terms (of the local population). A full list of equations is provided in Appendix 4.A.1.

HOUSEHOLDS

The currency union has a continuum of households of mass one. Households can have the preference types s or b . Each period, a share of household $(1 - \delta) \in (0, 1)$ is randomly drawn to change their region of residence and type. These households are assigned to Home with a probability of $\theta \in (0, 1)$ and Foreign with a probability of $1 - \theta$. After being relocated, households have a probability of π_s to be endowed with a type s preference and a probability of $\pi_b = 1 - \pi_s$ to have a type b preference.

Let $\tau \in \{s, b\}$ stand for the preference type. Each household maximizes its expected discounted utility of consumption $c_{\tau,t}$ and labor supply $h_{\tau,t}$

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\xi_{\tau} \frac{c_{\tau,t}^{1-\sigma}}{1-\sigma} - \psi_{\tau} \frac{h_{\tau,t}^{1+v}}{1+v} \right]$$

subject to a flow budget constraint. \mathbb{E} is the mathematical expectation, $\beta \in (0, 1)$ is the intertemporal discount factor, $\sigma > 0$ the inverse of intertemporal elasticity of substitution, $v > 0$ the inverse of Frisch elasticity of labor supply. The difference in preference is reflected in $\xi_b > \xi_s$. This difference generates a role for financial intermediaries, and in equilibrium, every household of type s is a saver while type b households are borrowers.

Household consumption is a composite good of Home and Foreign goods-bundle ($c_{H,t}$ and $c_{F,t}$):

$$c_t = \frac{c_{H,t}^{\theta} c_{F,t}^{1-\theta}}{\theta^{\theta} (1-\theta)^{1-\theta}}.$$

4.2. The model framework

Each goods-bundle itself is a Dixit-Stiglitz aggregator of differentiated goods produced by local firm j , with $j \in [0, \theta]$ located in Home and $j \in [\theta, 1]$ in Foreign:

$$c_{H,t} = \left[\left(\frac{1}{\theta} \right)^{\frac{1}{\mu}} \int_0^{\theta} c_{H,t}(j)^{\frac{\mu-1}{\mu}} dj \right]^{\frac{\mu}{\mu-1}}, \quad c_{F,t} = \left[\left(\frac{1}{1-\theta} \right)^{\frac{1}{\mu}} \int_{\theta}^1 c_{F,t}(j)^{\frac{\mu-1}{\mu}} dj \right]^{\frac{\mu}{\mu-1}}.$$

$\mu > 1$ denotes the price elasticity of substitution. Law of one price applies at the individual goods level, thus the consumer price index for both Home and Foreign households is given by

$$P_t = P_t^* = P_{H,t}^{\theta} P_{F,t}^{1-\theta},$$

where $P_{H,t}(j)$ and $P_{F,t}(j)$ are the prices for $c_{H,t}(j)$ and $c_{F,t}(j)$ respectively:

$$P_{H,t} = \left(\frac{1}{\theta} \int_0^{\theta} P_{H,t}(j)^{1-\mu} dj \right)^{\frac{1}{1-\mu}}, \quad P_{F,t} = \left(\frac{1}{1-\theta} \int_{\theta}^1 P_{F,t}(j)^{1-\mu} dj \right)^{\frac{1}{1-\mu}}.$$

All households have access to financial intermediaries. Households can save at the financial intermediaries by purchasing one-period risk-free discount bonds at the price q_t , which equals to the inverse of the risk-free policy rate set by the central bank. Households can also take up one-period loans from the financial intermediaries. The loans require a nominal repayment of one unit at maturity and have the prices q_t^b for Home borrowers and q_t^{b*} for Foreign borrowers.

An alternative investment option for the households is *local* government debts, which are priced at q_t^g for Home government or q_t^{g*} for Foreign. Different from Corsetti et al. (2014), I model the government debt as a long-term bond. Following Chatterjee and Eyigungor (2012), it is assumed that each period, a randomly drawn fraction η of the outstanding government bonds matures. The non-maturing government bonds pay out a coupon r (on the face value). Investments in government bonds are subject to default risk. At the very beginning of period t , before the selection of households to change types/locations, the local government defaults on its bonds with some probability p_t (described in more detail below). If it defaults, there is a haircut of $\vartheta \in [0, 1]$. It is assumed that the governments cannot discriminate between the maturing and the non-maturing bonds so that when a default happens, the haircut will apply to all payments as well as the nominal value of the remaining

4.2. The model framework

bonds. The defaulting government makes a lump-sum transfer T_t^c to its bondholders, and the transfer equals to the defaulted amount.⁶ Let B_{t-1}^g denote the total face value of government at the beginning of the period, then $T_t^c = \vartheta B_{t-1}^g [(1 - \eta) q_t^g + \eta + (1 - \eta) r]$.

To keep the model tractable, I follow Corsetti et al. (2013, 2014) and assume that after the possible type/location changes but before households' consumption and work decision, they join a large family with other households of the same type and same region. They pool their assets within the family. Thus all households of a particular type and location have the same marginal utility of income.⁷

Let B_t represent the face value of the one-period loan borrowed in period t and maturing in period $t + 1$ and S_t the face value of risk-free discount bonds. The combined nominal wealth A_t^{s-} of Home type s households just before the selection of type/location changing households is

$$A_t^{s-} = S_{t-1} + (1 - \vartheta_t) B_{t-1}^g [(1 - \eta)(q_t^g + r) + \eta] + T_t^c$$

with $\vartheta_t = \vartheta$ in the case of default, $B_{t-1}^g(1 - \eta)(q_t^g + r)$ the coupon payment and market value of the non-maturing government bonds and $B_{t-1}^g \eta$ the repayment of maturing government bonds. The combined nominal wealth of Home type b households is

$$A_t^{b-} = B_{t-1}.$$

Let A_t^+ denote the per capita wealth of households that have been selected to change type/location, then $A_t^+ = \theta(A_t^{s-} + A_t^{b-}) + (1 - \theta)(A_t^{s-*} + A_t^{b-*})$.

The flow budget constraint of Home type s household is

$$\begin{aligned} S_t q_t + B_t^g q_t^g &= \delta [S_{t-1} + B_{t-1}^g [(1 - \eta)(q_t^g + r) + \eta]] \\ &+ \pi_s (1 - \delta) A_t^+ - \pi_s X_{s,t} \end{aligned}$$

with $X_{s,t} = P_t c_{s,t} - w_t P_t h_{s,t} - D_{H,t}^f - D_t^{int} + T_t^g$ denoting the per capita net expenditure. w_t is the Home real wage level, $D_{H,t}^f$ are dividends paid by Home firms to Home households, $D_t^{int} = \theta(S_t q_t - B_t q_t^b) + (1 - \theta)(S_t^* q_t - B_t^* q_t^{b*})$ are dividends paid by international financial

⁶This assumption, while not affecting individual households' portfolio decision, allows the model to abstract from consequences of defaults on the debt level, and instead focus on how sovereign default risks affect returns on government bonds, which in turn influence private-sector spreads.

⁷This helps to reduce the dimension concerning heterogeneity of households to the four types and avoid the necessity to keep track of the history of moving.

4.2. The model framework

intermediaries to Home household and finally, T_t^g denotes taxes paid to Home government. All $D_{H,t}^f$, D_t^{int} and T_t^g are paid in lump-sum fashion. Similarly, the budget constraint of Home borrower household is

$$B_t q_t^b = \delta B_{t-1} - \pi_b(1 - \delta)A_t^\dagger + \pi_b X_{b,t}$$

with $X_{b,t} = P_t c_{b,t} - w_t P_t h_{b,t} - D_{H,t}^f - D_t^{int} + T_t^g$.

Let $\lambda_{\tau,t}$ denote the marginal utility of income, the optimizing behavior of the Home households further yields the following Euler equations:

$$\begin{aligned} q_t &= \beta \mathbb{E}_t \left\{ \frac{\delta \lambda_{s,t+1} + (1 - \delta) \bar{\lambda}_{t+1}}{\lambda_{s,t} \Pi_{t+1}} \right\}, \\ q_t^g &= \beta \mathbb{E}_t \left\{ (1 - \vartheta \mathbf{p}_{t+1}) [\eta + (1 - \eta)(r + q_{t+1}^g)] \frac{\delta \lambda_{s,t+1} + (1 - \delta) \bar{\lambda}_{t+1}}{\lambda_{s,t} \Pi_{t+1}} \right\}, \\ q_t^b &= \beta \mathbb{E}_t \left\{ \frac{\delta \lambda_{b,t+1} + (1 - \delta) \bar{\lambda}_{t+1}}{\lambda_{b,t} \Pi_{t+1}} \right\} \end{aligned}$$

with the gross inflation rate $\Pi_{t+1} = P_{t+1}/P_t$ and the average marginal utility of income $\bar{\lambda}_t = \theta(\pi_b \lambda_{b,t} + \pi_s \lambda_{s,t}) + (1 - \theta)(\pi_b \lambda_{b,t}^* + \pi_s \lambda_{s,t}^*)$.

FIRMS

A continuum of firms in Home and Foreign produce differentiated goods. Firm j produces with local labor h_t and a linear production technology $y_t(j) = z_t h_t(j)$. z_t is the region-specific technology level. Firms are subject to monopolistic competition and sticky prices as in Calvo (1983). In each period, a fraction $(1 - \alpha)$ of them may re-optimize their prices, and they set the new prices to maximize expected discounted profits. The rest of the firms increase their prices by the steady state rate of inflation Π .

FINANCIAL INTERMEDIARIES

Financial intermediaries in the currency union are perfectly competitive. They collect deposits from both savers from Home and Foreign at the price q_t and lend to Home borrowers at the price q_t^b and Foreign borrowers at the price q_t^{b*} . It is assumed that borrowings are associated with a higher interest rate than deposits, resulting in region-specific non-negative

4.2. The model framework

interest spreads:⁸

$$1 + \omega_t = q_t/q_t^b \geq 0, \quad 1 + \omega_t^* = q_t/q_t^{b*} \geq 0.$$

Financial intermediaries collect the largest quantity of deposits that can be repaid with the proceeds from the loans. This means that the private saving and lending have to satisfy the following union-wide condition:

$$\theta S_t^p + (1 - \theta) S_t^{p*} = \theta B_t + (1 - \theta) B_t^*.$$

As a result, the beginning of period wealth can be written as

$$A_t^\dagger = \theta B_{t-1}^g [(1 - \eta)(q_t^g + r) + \eta] + (1 - \theta) B_{t-1}^{g*} [(1 - \eta)(q_t^{g*} + r^*) + \eta].$$

GOVERNMENT AND THE SOVEREIGN RISK SPILLOVER

Governments each carry out their own fiscal policy: they consume the composite good (g_t or g_t^*), collect lump-sum taxes (T_t^g or T_t^{g*}) from local households and finance the deficits with government bonds (B_t^g or B_t^{g*}). Each period a fraction η of the outstanding government bonds mature while the remaining government bonds pay out a coupon r . The average maturity of the government bonds is $1/\eta$, and the one-period bond case is nested in the model as the special case of $\eta = 1$.

At the beginning of each period before the type changes play out, governments may choose to default but cannot discriminate between the maturing and the remaining debt. As described before, in case of default the defaulted amount of government bonds is returned in lump-sum fashion to bond holders. It follows that Home government's budget constraint in per capita terms satisfies

$$[B_t^g - (1 - \eta) B_{t-1}^g] q_t^g = [\eta + (1 - \eta) r] B_{t-1}^g - T_t^g + P_t g_t.$$

The tax is increasing in output y_t and also serves to stabilize government debt level in the

⁸One way to rationalize the spread is to assume that the issuance of loans is costly. For example in Cúrdia and Woodford (2010, 2016) and Corsetti et al. (2013, 2014), a fraction of the issued loans in the Home and Foreign regions are assumed to be unrecoverable.

4.2. The model framework

long run

$$T_t^g = P_t t^g + \phi_{T,y} P_t y_t + \phi_{T,b^g} B_{t-1}^g,$$

with $\phi_{T,y} > 0$, $\phi_{T,b^g} > 0$.

The default probability is modeled as a function of the government real debt level b_t^g .⁹ In particular, similar to Corsetti et al. (2013, 2014) I assume that the default probability p_{t+1} , is determined with a *beta*-distribution:

$$p_{t+1} = F_{beta} \left(\frac{b_t^g}{4y} \frac{1}{b^{g,max}}; \alpha_{b^g}, \beta_{b^g} \right)$$

where y is the steady state level of total Home output and $b^{g,max}$ the highest debt-to-GDP ratio that can be supported.

Because of default risks, in equilibrium, returns on government bonds have to be higher than an otherwise identical but risk-free bond. I calculate this risk premia ω_t^g using the ratio of the internal rate of return of government bonds R_t^g and the return R_t^{g,r^f} of a *fictional* risk-free bond with the same maturity structure and coupon: $1 + \omega_t^g = R_t^g / R_t^{g,r^f}$. The internal rate of return of government bonds is pinned down by the relation $q_t^g = [\eta + (1 - \eta) r] / [R_t^g - (1 - \eta)]$; the *fictional* bond's return is implicitly defined in $q_t^{g,r^f} = [\eta + (1 - \eta) r] / [R_t^{g,r^f} - (1 - \eta)]$ and $q_t^{g,r^f} = \beta \mathbb{E}_t \left\{ [\eta + (1 - \eta)(r + q_{t+1}^{g,r^f})] [\delta \lambda_{s,t+1} + (1 - \delta) \bar{\lambda}_{t+1}] / (\lambda_{s,t} \Pi_{t+1}) \right\}$.

To reflect the sovereign risk spillover, it is assumed that the private-sector spreads between borrowers and savers are influenced by the default risk of governments. In particular, the Home for example, the private borrowing spread increases with the spread on the government bonds:

$$1 + \omega_t = \chi_\psi \left(\frac{R_t^g}{R_t^{g,r^f}} \right)^{\alpha_\psi} \exp(s_t)$$

where parameters $\chi_\psi > 0$ and $\alpha_\psi > 0$ capture the exposure of a country's private-sector funding condition to its sovereign default risk and s_t is a private sector financial shock.

⁹The theoretical literature on sovereign default has highlighted the importance of government indebtedness in determining the default probability. See for example Eaton and Gersovitz (1981) and Arellano (2008). While the theory also suggests that output level is crucial in shaping the default decision, the empirical evidence is weaker Tomz and Wright (2007).

4.3. Sovereign risk spillover and shock transmissions

GOODS AND LABOR MARKET CLEARING

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

$$\begin{aligned} y_t &= \left(\frac{P_{H,t}}{P_t} \right)^{-1} \left[\theta(c_t + g) + (1 - \theta)(c_t^* + g^*) \right], \\ y_t^* &= \left(\frac{P_{F,t}}{P_t} \right)^{-1} \left[\theta(c_t + g) + (1 - \theta)(c_t^* + g^*) \right]. \end{aligned}$$

$$\begin{aligned} y_t \Delta_{H,t} &= z_t h_t, & h_t &= \pi_s h_{s,t} + \pi_b h_{b,t}, \\ y_t^* \Delta_{F,t} &= z_t^* h_t^*, & h_t^* &= \pi_s h_{s,t}^* + \pi_b h_{b,t}^*. \end{aligned}$$

$\Delta_{H,t} = \frac{1}{\theta} \int_0^\theta \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\mu} dj$ and $\Delta_{F,t} = \frac{1}{1-\theta} \int_\theta^1 \left(\frac{P_{F,t}(j)}{P_{F,t}} \right)^{-\mu} dj$ are measurements of price dispersion.

4.3 Sovereign risk spillover and shock transmissions

Before turning to optimal monetary policy, it is useful first to examine how the sovereign risk spillover affects the economy. For this, I look at the effect of the spillover on different shock transmissions under a specific monetary policy – the simple Taylor rule.

The model is log-linearized around the efficient steady state.¹⁰ The log-linearized model is first summarized in the following to provide analytical insights into how the sovereign risk spillover channel affects the otherwise standard New Keynesian model.¹¹ After that, the model is calibrated to the euro area to quantify the effects.

Regarding notation, unless otherwise noted, $\hat{x}_t = \log(x_t/x)$ is the log-derivation of variable x_t from its steady state value x . Bar indicates union average variables, i.e., $\bar{\hat{x}}_t = \theta \hat{x}_t + (1 - \theta) \hat{x}_t^*$. D denotes the difference between Home and Foreign variables: $\hat{x}_t^D = \hat{x}_t - \hat{x}_t^*$. Finally, Δ expresses first differences of variables: $\Delta \hat{x}_t = \hat{x}_t - \hat{x}_{t-1}$.

¹⁰In particular, at the efficient steady state, consumer price inflation equals $\bar{\Pi}$ and private sector spreads in both countries equal zero. More details about the efficient steady state are provided in Appendix 4.A.2.

¹¹The derivation of the equations is provided in Appendix 4.A.4.

4.3. Sovereign risk spillover and shock transmissions

4.3.1 Log-linearized structural relations

The demand side of the model is represented by the union-wide dynamic IS curve. Denote average output \bar{y}_t , the risk-free short-term policy rate $\hat{R}_t = -\log(q_t/\bar{q})$. And define average government spending shock as $\bar{g}_t = \theta(g_t - \bar{g}) + (1 - \theta)(g_t^* - \bar{g}^*)$, the union-wide average level of private sector interest spreads as $\bar{\omega}_t = \theta \log[(1 + \omega_t)/(1 + \omega)] + (1 - \theta) \log[(1 + \omega_t^*)/(1 + \omega^*)]$. The dynamic IS curve is

$$\begin{aligned} \bar{y}_t &= \mathbb{E}_t \bar{y}_{t+1} - \mathbb{E}_t \Delta \bar{g}_{t+1} \\ &\quad - \frac{1}{\sigma} \left[(\hat{R}_t + \pi_b \bar{\omega}_t) - \mathbb{E}_t \hat{\Pi}_{t+1} - S_\lambda \mathbb{E}_t \Delta \bar{\lambda}_{R,t+1} \right]. \end{aligned} \quad (4.1)$$

with $S_\lambda = \pi_s \pi_b (c_s - c_b)$. As in the dynamic IS relation derived in Cúrdia and Woodford (2010), the average interest rate $(\hat{R}_t + \pi_b \bar{\omega}_t)$ now takes the place of the risk-free policy rate in determining the aggregate demand. Moreover, as the private sector spreads only apply to borrowers, their variations cause different reactions in savers and borrowers' consumption, resulting in a wedge between their marginal utility of income $\bar{\lambda}_{R,t} = \theta(\hat{\lambda}_{s,t} - \hat{\lambda}_{b,t}) + (1 - \theta)(\hat{\lambda}_{s,t}^* - \hat{\lambda}_{b,t}^*)$. The relative marginal utility $\bar{\lambda}_{R,t}$ measures the union-wide level of distributional inefficiency due to the credit spread and it evolves according to

$$\bar{\lambda}_{R,t} = -\bar{\omega}_t + \delta \mathbb{E}_t \bar{\lambda}_{R,t+1}. \quad (4.2)$$

An increase in union-wide average spread in the private sector, which will be reflected in an increase of $\bar{\lambda}_{R,t} < 0$ according to (4.2), can be recessionary. This is case when in steady state savers' consumption is greater than that of borrowers' ($S_\lambda > 0$), as in the later calibrated exercise.

The aggregate supply side of the model can be summarized in the union-wide Phillips curve that links the union-wide inflation $\hat{\Pi}_t$ to the union-wide output gap:

$$\hat{\Pi}_t = \beta \mathbb{E}_t \hat{\Pi}_{t+1} + \kappa \bar{y}_t + \kappa_\lambda \bar{\lambda}_{R,t} + \frac{\kappa}{v + \sigma} [\bar{u}_t - (v + 1) \bar{z}_t - \sigma \bar{g}_t] \quad (4.3)$$

with $\kappa = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}(v + \sigma)$, $\kappa_\lambda = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha} [S_\lambda + \pi_s(1 - h_s/h)]$, and \bar{u}_t represent the average markup shock. The Phillips curve again is a straight forward extension of the Cúrdia and Woodford (2010) Phillips curve to an open economy context. It resembles the traditional New Keynesian Phillips curve but with an additional term that accounts for the effect of credit spreads. A (union-wide average) positive spread in the private sector is

4.3. Sovereign risk spillover and shock transmissions

deflationary because positive spreads, besides the effect on output, increase the borrowers' marginal utility of income and thus also increases their incentive to work at a lower wage.

The supply block of the economy is completed with the following equation for the terms of trade $\tau_t = P_{H,t}/P_{F,t}$:

$$\Delta \hat{\tau}_t = \beta \mathbb{E}_t \Delta \hat{\tau}_{t+1} + \mathcal{K} \left[- (v + 1) \hat{\tau}_t + z \pi_b h_b \hat{\lambda}_{R,t}^D + u_t^D - (v + 1) \hat{z}_t^D \right]. \quad (4.4)$$

The terms of trade is driven by differences in the technology levels and differences in markup shocks. As a result of credit spreads, it is, in addition, affected by $\hat{\lambda}_{R,t}^D$ – the cross-region difference between savers-borrowers- relative marginal utility. This difference between the relative marginal utility $\hat{\lambda}_{R,t}^D$ is a result of the different level of credit spreads in Home and Foreign:

$$\hat{\lambda}_{R,t}^D = -\hat{\omega}_t^D + \delta \mathbb{E}_t \hat{\lambda}_{R,t+1}^D. \quad (4.5)$$

If a region has a higher credit spread, its borrowers are willing to work at a lower wage than the other region. This reduces the marginal costs in the region with higher spreads and thus affects the terms of trade.

Equations (4.1) - (4.5) demonstrate how credit spread is incorporated in an otherwise standard New Keynesian model of a currency union. The drivers of the spreads, however, remain to be specified. With the sovereign risk spillover, the private sector spreads (average and difference) are determined by the sovereign risk premia:

$$\bar{\hat{\omega}}_t = \alpha_\psi [\theta \hat{\omega}_t^g + (1 - \theta) \hat{\omega}_t^{g*}] + \bar{s}_t, \quad (4.6)$$

$$\hat{\omega}_t^D = \alpha_\psi (\hat{\omega}_t^g - \hat{\omega}_t^{g*}) + s_t^D, \quad (4.7)$$

where \bar{s}_t is the average, and s_t^D the cross-region difference of the private sector financial shocks.

The risk premia on the government bonds depend on the public sector indebtedness, which is described in the following equation:

$$\hat{b}_t^g = \chi_g \hat{b}_{t-1}^g - \chi_g \hat{\Pi}_t - \frac{1}{b^g q^g} (\phi_{T,y} \hat{y}_t - \tilde{g}_t) - \left(1 - \frac{1 - \eta}{\Pi}\right) \hat{q}_t^g + \epsilon_t^g, \quad (4.8)$$

with $\chi_g = [\eta + (1 - \eta)(r + q^g) - \phi_{T,b^g}]/(\Pi q^g)$. The current Home government's real debt level is high if it has inherited a high debt level \hat{b}_{t-1}^g from last period. It is also high if current

4.3. Sovereign risk spillover and shock transmissions

inflation $\hat{\Pi}_t$ is low and fiscal deficit $(\phi_{T,y}\hat{y}_t - \tilde{g}_t)$ is high, or if the government bond price \hat{q}_t^g is low. Finally, the indebtedness can be affected by ϵ_t^g , a shock to the government indebtedness. Sovereign default risks affect the government indebtedness through the government bond price, and the bond price evolves according to:

$$\hat{q}_t^g = -\hat{R}_t + \frac{(1-\eta)q^g}{\eta + (1-\eta)(r+q^g)} \mathbb{E}_t \hat{q}_{t+1}^g - \frac{\vartheta \mathbf{p}}{1-\vartheta \mathbf{p}} \left(F'_{beta} \frac{b^g}{\mathbf{p}} \hat{b}_t^g + \epsilon_t^g \right), \quad (4.9)$$

where F'_{beta} is the first derivative of default probability with respect to government debt and evaluated in steady state and ϵ_t^g is a default probability shock. Absent default risks, the bond price would be determined by risk-free rate and the expected future bond price (the first two terms in (4.9)). Default risks, reflected in the last term of the equation, reduce the bond price.

Finally, the government bond spread is pinned down the following equation.

$$\begin{aligned} \hat{\omega}_t^g &= (1-\eta)q \left(\mathbb{E}_t \hat{\omega}_{t+1}^g + \chi \vartheta \mathbf{p} \mathbb{E}_t \hat{q}_{t+1}^g + \vartheta \mathbf{p} \hat{R}_t \right) \\ &\quad + \chi \frac{\vartheta \mathbf{p}}{1-\vartheta \mathbf{p}} \left(F'_{beta} \frac{b^g}{\mathbf{p}} \hat{b}_t^g + \epsilon_t^g \right), \end{aligned} \quad (4.10)$$

where $\chi = [1 - (1-\eta)q(1-\vartheta \mathbf{p})]$. Just like government bond price, the current spread reflects the expected development of future spread, bond price, and the current risk free rate. It also increases with government indebtedness. With plausible calibration of the steady state default probability \mathbf{p} – which is normally low for the euro area countries, the latter effect will be the driving force of the government bond spread.

In the following, I will first describe the model calibration, and then analyze the drivers of the government debt level and how it depends on the maturity structure of the government bonds. This will serve as a basis for us to understand the effect of sovereign risk spillover on the propagation of disturbances in the numerical analysis later in the section.

4.3.2 Model calibration

The model is calibrated to the euro area on a quarterly basis. Most of parameters are assumed to be the same across regions. The exceptions are their population sizes and government debt levels. Some parameters are chosen directly, while others are calibrated to target certain steady state relations. Many parameters are also present in the canonical version of New Keynesian model or Corsetti et al. (2013, 2014). In these cases, I use values

4.3. Sovereign risk spillover and shock transmissions

from the literature. The calibration is summarized in Table 4.1.

Home corresponds to the core euro area countries and has population θ of two third. Both regions are assumed to have equal size of savers and borrowers. With $\delta = 0.95$, the expected time for which households stay the current type is five years, as in Corsetti et al. (2014).

Turning to household's utility parameters, the time discount factor β is chosen such that the steady state risk-free rate equals 4.5% (annualized). The intertemporal elasticity of substitution takes a value widely assumed in the literature, and the Frisch elasticity of labor supply is in line with Hall (2009). The scaling parameter of type s households ξ_s is normalized to 1. The other scales parameters ξ_b , ψ_s and ψ_b are chosen such that the average private debt to annual GDP in the currency union amounts to 130%, steady state labor supplies of the two types of households are equalized, and the steady state output in Home is normalized to one.

With respect to the firm side, I follow Corsetti et al. (2013) and set the Calvo parameter at $\alpha = 0.925$. $\mu = 7.66$ to achieve a gross markup of 1.15, and the steady state inflation is assumed to be 2% (annualized). The steady state aggregate hours worked is targeted at $1/3$, leading to $\bar{z} = 3$.

The government expenditure in steady state is set to 20% of annual total output. The response of taxes to output $\phi_{T,y} = 0.5$, while $\phi_{T,bg}$ is chosen to be large enough to eventually stabilize government bonds.¹² In steady state, Home has a public-debt-to-GDP ratio $\bar{b}^g/(4 * \bar{y})$ of 93% and Foreign has a higher government indebtedness of 126%.¹³ The average maturity of the government bonds is assumed to be six years, consistent with Lojsch et al. (2011). For simplicity, zero coupons are assumed.

The calibration of parameters concerning the sovereign risk and the spillover to private sector follows closely Corsetti et al. (2013, 2014). The degree of spillover is pinned down by the elasticity $\alpha^\psi = 0.55$ as estimated in Harjes (2011). $\chi^\psi = 0.998$ is calibrated to achieve zero steady state private sector credit spread, required for an efficient steady state. The beta-distribution determining the sovereign default probability is parameterized with

¹²The minimum $\phi_{T,bg}$ required to stabilize debt, in the long run, depends on the average maturity of the debt. The shorter the maturity, the larger the tax response needs to be. To keep the parameter fixed when comparing short-term and long-term government bonds, $\phi_{T,bg}$ is as the minimum value sufficient to stabilize one-period bonds.

¹³The ratios are calculated with general government debt as projected in the IMF's April 2012 WEO, plus estimated contingent liabilities related to financial sector support. See Corsetti et al. (2014) and the reference therein.

4.3. Sovereign risk spillover and shock transmissions

the $\alpha^{b^g} = 3.70$, $\beta^{b^g} = 0.54$, $b_{max}^g = 2.56$. These parameters are calibrated to match the relationship between public debt level and 5-year CDS spread in a sample of industrialized economies.¹⁴ Haircut ϑ is set to 0.55, in the middle range of the empirical evidence provided in Sturzenegger and Zettelmeyer (2008).

Table 4.1: Calibration

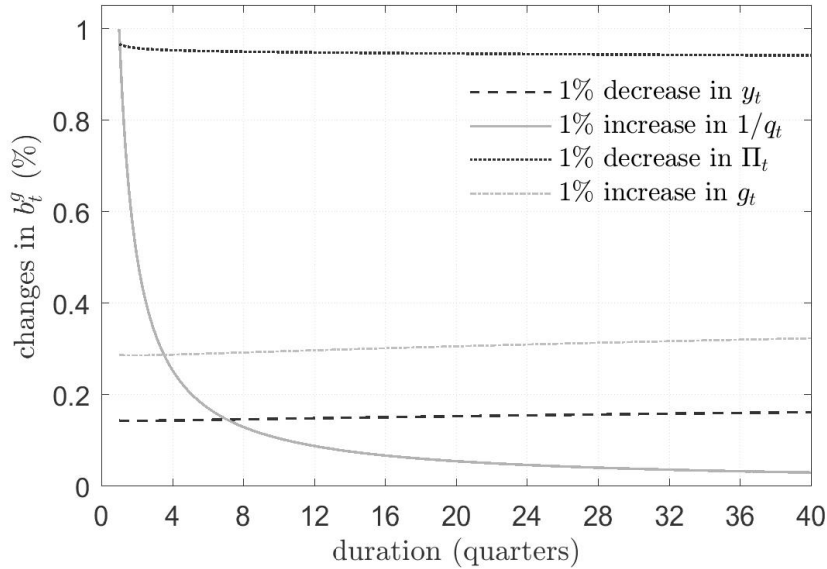
Baseline model parameters		Value
Home population size	θ	2/3
Saver population size	π_s	1/2
Probability of type changing	$1 - \delta$	1 - 0.95
Time discount rate	β	0.994
Intertemporal elasticity of substitution	$1/\sigma$	1/2
Frisch elasticity of labor supply	ν	1/1.9
Consumption utility parameter: s	ξ_s	1
Consumption utility parameter: b	ξ_b	0.02
Labor utility parameter	ψ_s, ψ_b	2.74
Price rigidity Calvo parameter	α	0.925
Markup	$\mu/(\mu - 1)$	1.15
Steady state inflation	Π	1.005
Steady state technology level	z	3
Steady state government expenditure/output	g/y	20%
Tax sensitivity to output	$\phi_{T,y}$	0.5
Tax sensitivity to debt level	ϕ_{T,b^g}	0.078
Steady state government debt/GDP: Home	$b^g/(4y)$	93%
Steady state government debt/GDP: Foreign	$b^{g^*}/(4y^*)$	126%
Government bond coupon	r	0
Government bond duration	η	1/24
Sovereign risk spillover parameter	α^ψ	0.55
Sovereign risk spillover parameter	χ^ψ	0.998
Default risk parameter	α^{b^g}	3.7
Default risk parameter	β^{b^g}	0.54
Default haircut	ϑ	0.55

All exogenous disturbances - except shock to the sovereign debt level - are assumed to follow an AR(1) process in the form of $x_t = \rho x_{t-1} + \epsilon_t^x$, where ϵ_t^x i.i.d. distributed with mean zero and the persistence parameter ρ is fixed at 0.75. The sovereign debt shock is assumed to be transitory.

¹⁴The steady state (nonlinear) relation between sovereign debt spread and the debt level is independent of the maturity structure. In steady state $R^g/R^{g,r^f} = 1/[1 - \vartheta F_{beta}(b^g)]$, thus we can still rely on Corsetti et al. (2013)'s estimation despite introducing long-maturity debts.

4.3. Sovereign risk spillover and shock transmissions

Figure 4.1: Determinants of government debt level and the bond maturity



4.3.3 Maturity

Equations (4.8) and (4.9) show that the government indebtedness is determined by its own lagged value, the current output and inflation, as well as current policy rate and expected future bond prices. As a shock directly moves output, inflation, and indirectly the risk-free rate, its effect on the public debt level through each of these endogenous variables depends on the maturity structure of the government bonds. To illustrate, Figure 4.1 plots the impact of a one-percentage change in Home variables on the Home government debt level under the calibration described above. The impact is plotted for as a function of the debt maturity, and for simplicity, it is assumed that the government bond price returns to its steady state level in the next period.

While the impact of output and inflation on government debt level is not sensitive to the average duration of the government debt, the impact of the risk-free rate on the indebtedness decreases steeply with the maturity. Under the model calibration with an average maturity of 24 quarters, the impact of the policy rate is much smaller than that of the inflation and output. If instead, government bonds are short-term, changes in the risk-free rate would trigger a much larger change in the sovereign debt level. This translates

4.3. Sovereign risk spillover and shock transmissions

into different magnitudes of effect on shock transmissions due to sovereign risk spillover for short-term and long-term public debt.

4.3.4 Sovereign risk spillover and shock transmissions

The quantitative impact of sovereign risk spillover on shock propagation can be illustrated under the often-studied standard Taylor rule:

$$\hat{R}_t = \phi_\pi \hat{\Pi}_t + \phi_y \bar{y}_t + \epsilon_t^r,$$

with ϵ_t^r a monetary policy shock, $\phi_\pi = 1.5$, and $\phi_y = 0.5/4$.

Figures 4.2 - 4.4 illustrate the impact of the sovereign risk spillover by looking at the responses of key union-average variables to a set of union-level shocks.¹⁵ The impulse responses are compared in three different setups: (1) no sovereign risk spillover, labeled ‘Exog’, a case where credit spreads do not depend on sovereign risk; (2) with sovereign risk spillover under the baseline long-term debt calibration, labeled ‘SovFF’; (3) with sovereign risk spillover and one-period government bonds, labeled ‘SovFF_{ST}’.

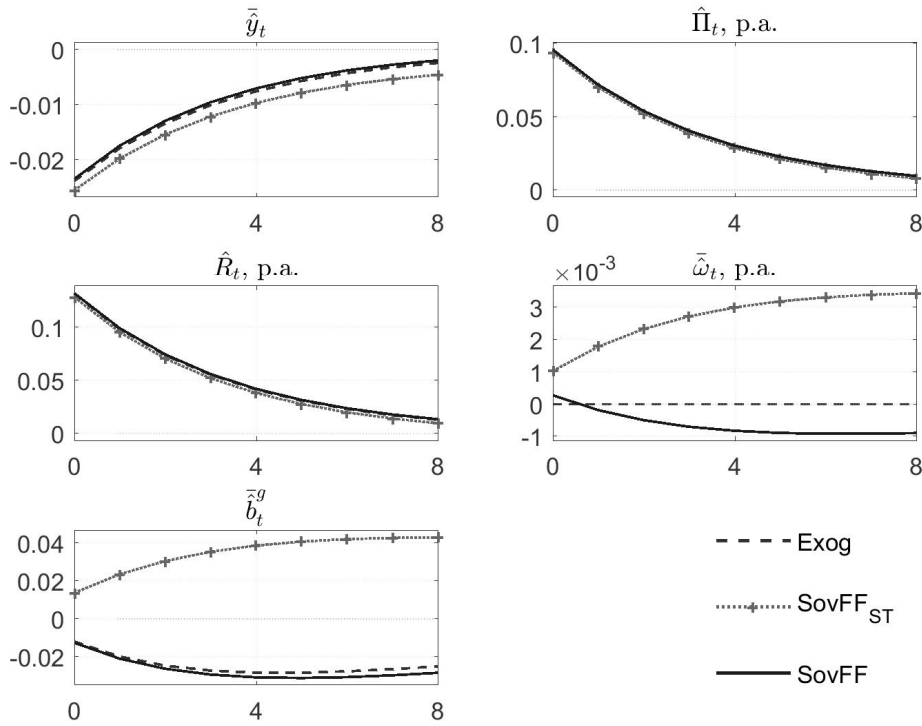
Figure 4.2 shows the responses to a union-wide cost-push shock. Absent the risk spillover, the ‘Exog’ case, the shock does not trigger any movement in the spreads. Output and inflation dynamics are as expected in a basic NK model and the government indebtedness decreases mainly because of inflation and despite the lower output and higher interest rate. Notice that as the government debt is irrelevant in the ‘Exog’ case, the impulse responses of output, inflation and policy rate are the same for different government bond maturities. Under the baseline calibration with long-term government bonds and sovereign risk spillover, the public debt level evolves similarly to that in the ‘Exog’ case. Now, with the spillover, the lower government debt level leads to a lower level of private sector spread. This slightly ameliorates the drop in output and has negligible impact on inflation. Moreover, the impact of the sovereign spillover is much limited that the risk-free rate dynamic is indistinguishable from the ‘Exog’ case.

The interest rate dynamic in the case with short-term government debt is also very similar to that of the other two cases. However, the impact of the sovereign risk spillover on the shock propagation is somewhat different. Because of the short maturity, the increase in interest rate outweighs inflation in driving up government indebtedness, leading to an

¹⁵Union-level shocks hit both regions simultaneously. This allows us to abstract from the regional asymmetry and to focus on the impact of the existence of the sovereign risk spillover.

4.3. Sovereign risk spillover and shock transmissions

Figure 4.2: Impulse responses under the Taylor rule: cost-push shocks



Impulse response of endogenous model variables to 1% cost-push shocks in Home and Foreign (u and u^*). Variable are plotted as percentage point derivation from the steady state. p.a. = annualized.

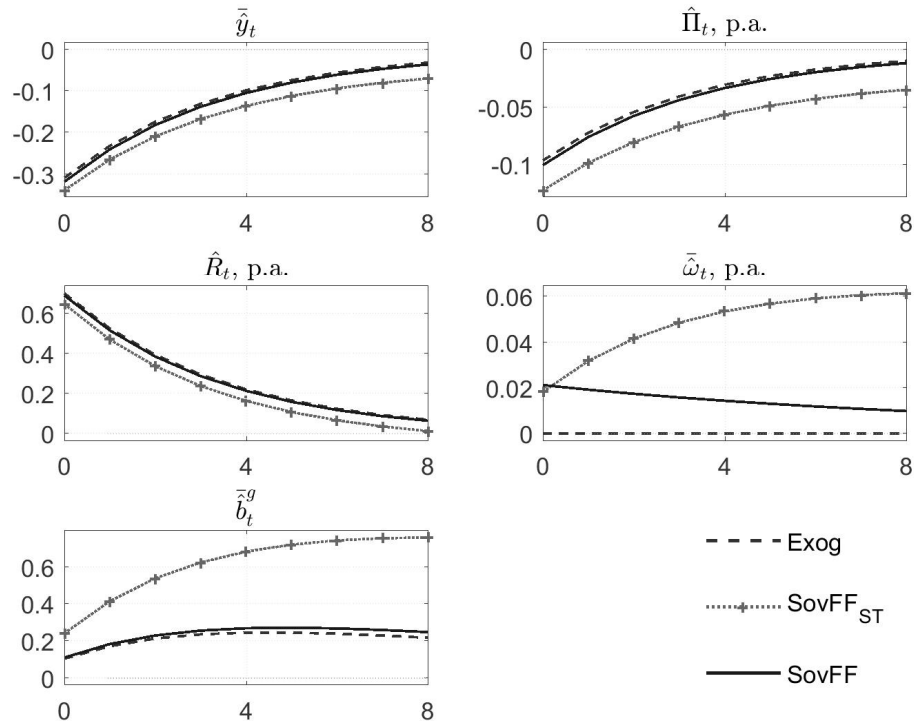
amplification of the recession.

In the case of a monetary policy shock (Figure 4.3), there is again a stark contrast of the impact of the spillover when government debt is short-term to when it is long-term. Without the spillover, a contractionary monetary policy shock is associated with a drop in output and inflation, and as a result an increase in government debt. The low output and inflation contribute to the increase in government indebtedness, which in turn, exacerbates the downward pressure on output and inflation. The magnitude of this amplification is larger if the government debt is short-term.

It is, however, not always the case that shocks that move output and inflation in the same direction will be amplified by the spillover. Suppose the government bond is short term, a shock that leads to recession and deflation would trigger an expansionary monetary

4.3. Sovereign risk spillover and shock transmissions

Figure 4.3: Impulse responses under the Taylor rule: monetary policy shock



Impulse response of endogenous model variables to a 1% (annualized) monetary policy shock (ϵ^r). Variable are plotted as percentage point derivation from the steady state. p.a. = annualized.

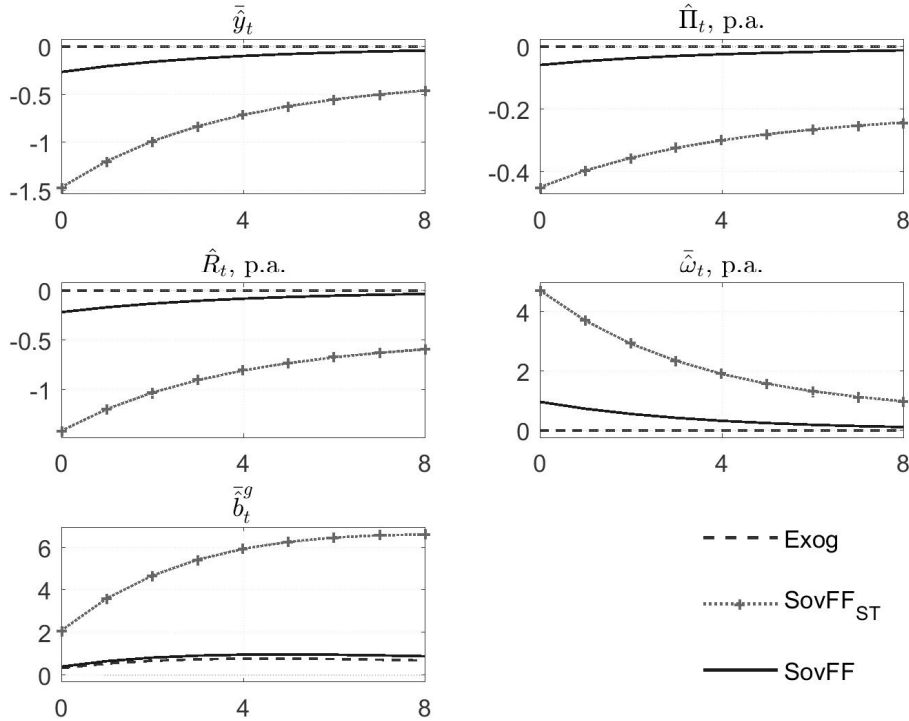
policy under Taylor rule. As short-term debt is strongly affected by changes in the policy rate, this might result in a drop in government indebtedness which in turn would weaken the disturbance's impact on inflation and output.¹⁶ Thus, given a shock, whether the sovereign risk spillover amplifies the shock transmission depends on the characteristic of the disturbance itself and the monetary policy, but also crucially on the maturity of the government bonds.

While the consequences of the sovereign risk spillover are limited under the Taylor rule in some cases, it put the sovereign indebtedness into a crucial role for model dynamics and allows significant impact for shocks that affect the fiscal position directly. Figure 4.4

¹⁶See, for example, the impulse responses to financial shocks that directly increase private sector spreads in Appendix 4.A.8.

4.3. Sovereign risk spillover and shock transmissions

Figure 4.4: Impulse responses under the Taylor rule: default probability shocks



Impulse response of endogenous model variables to default probability shocks that increase sovereign default probabilities in Home and Foreign by 5 percentage points initially (ϵ^p and ϵ^{p*}). Variable are plotted as percentage point derivation from the steady state. p.a. = annualized.

plots the impulse responses to a five percentage points increase in the default probability of government debt. This may be particularly interesting as, during the euro area debt crisis, we observe a sudden large increase in the government spreads in the periphery countries. The shock, which absent the sovereign risk spillover would be irrelevant for aggregate output and inflation, leads to a jump in about 100 basis points (annualized) in private sector spread, a drop in aggregate output as well as deflation. Again, the impact of the shock is quantitatively much large if the government debt is short-term. The intuition is that when government debt is short-term, a larger fraction of the debt would have to be refinanced at the low government bond prices. And the resulting higher level of government indebtedness reinforces the problem of high default probability and low bond price. A similar pattern is

4.4. Optimal monetary policy

observed in the case of a shock to the government debt level, see Appendix 4.A.8.

To sum up, we find that the maturity structure of government debt is critical for the effect of the sovereign risk spillover on shock transmissions. Assuming short-term government debt would largely increase the impact of the risk-free rate on the sovereign risk channel. Under the Taylor rule and a realistic calibration to the euro area with long-term government bonds, the impact of sovereign risk spillover is limited for shocks that do not affect fiscal positions directly, but more important for the transmission of shocks directly hit the fiscal position.

4.4 Optimal monetary policy

I now turn to examine how sovereign risk spillover affects optimal monetary policy – the policy that maximizes the union-wide welfare.

It is assumed that the central bank assigns equal weights to all households in the currency union. The objective function of the central bank is thus:

$$\begin{aligned} & \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \theta [\pi_s u_{s,t} + \pi_b u_{b,t}] + (1 - \theta) [\pi_s u_{s,t}^* + \pi_b u_{b,t}^*] \right\} \\ & = -\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t L_t + t.i.p. + \vartheta(\|\Xi\|^3) \end{aligned} \quad (4.11)$$

with $u_{\tau,t} = \xi_{\tau} c_{\tau,t}^{1-\sigma} / (1 - \sigma) - \psi_{\tau} h_{\tau,t}^{1+v} / (1 + v)$. Following Woodford (2003), I take the quadratic-linear approach and derive a welfare-loss function L_t of the objective function by taking a second-order approximation. *t.i.p.* stands for terms independent of policy and $\vartheta(\|\Xi\|^3)$ is a collection of approximation errors of the third order or higher. The second-order approximated welfare-loss function of the central bank is given by

$$\begin{aligned} L_t = & \theta(x_t)^2 + (1 - \theta)(x_t^*)^2 + \frac{\mu}{\kappa} \hat{\Pi}_t + \left[\frac{1 - \sigma}{v + \sigma} + \frac{\mu}{\kappa} \right] \theta(1 - \theta) \hat{\tau}^2 \\ & + \Omega(\tilde{\lambda}_{R,t})^2 + \Omega^D(\hat{\lambda}_{R,t}^D)^2 \end{aligned} \quad (4.12)$$

with $\Omega = \frac{1}{\sigma+v} \left(\frac{\pi_s c_s \pi_b c_b}{\sigma} + \frac{\pi_s \tilde{h}_s \pi_b \tilde{h}_b}{v} \right)$, $\Omega^D = \frac{\theta(1-\theta)}{\sigma+v} \left(\frac{\pi_b c_b}{\sigma} + \frac{\pi_s \tilde{h}_s \pi_b \tilde{h}_b}{v} \right)$ and $\tilde{h}_{\tau} = h_{\tau}/h$. x_t and x_t^*

4.4. Optimal monetary policy

is the deviation of the actual output from the efficient output defined as

$$x_t = \hat{y}_t - \hat{y}_t^e, \quad x_t^* = \hat{y}_t^* - \hat{y}_t^{e*}$$

$$\hat{y}_t^e = \frac{1}{v + \sigma} \left((v + 1)\hat{z}_t + \sigma\bar{g}_t \right), \quad \hat{y}_t^{e*} = \frac{1}{v + \sigma} \left((v + 1)\hat{z}_t^* + \sigma\bar{g}_t \right)$$

The derivation is provided in the Appendix 4.A.5.

The first four terms of the welfare-loss function ($\bar{\hat{y}}_t$ and $\bar{\hat{\Pi}}_t$) are standard components of the welfare-loss function of a NK currency union model.¹⁷ The last two terms emerge because of the credit spreads. The average marginal-utility gap ($\bar{\hat{\lambda}}_{R,t}$) is also seen in a similar form in Cúrdia and Woodford (2016) as a measurement of the distributional inefficiency between savers and borrowers. The importance of $\bar{\hat{\lambda}}_{R,t}$ relative to output decreases in $\sigma + v$ because - as is standard - large values of the “curvature” parameters implies a higher relative importance of output deviation from the welfare perspective. Aside from that, the weight of ($\bar{\hat{\lambda}}_{R,t}$) increases in steady state total consumption of savers and borrowers and the intertemporal elasticity of substitution. This is because deviations of marginal utility from its efficient level are related to larger variations in consumption level the larger intertemporal elasticity of substitution and the higher the steady state level of consumption is. Analogously, the weight of ($\bar{\hat{\lambda}}_{R,t}$) is also increasing in the steady state labor and the Frisch elasticity of labor supply. The last term in the welfare-loss function is the difference of marginal-utility gap. It reflects the distributional inefficiency between countries and appears because of the currency union setup. Its weight in the welfare-loss function differs from that of the average marginal-utility in two aspects. Firstly, it adjusts for the different sizes of the countries. Secondly, it reflects that the cross-countries distributional inefficiency is caused by the different levels of Home and Foreign borrower’s consumption. In fact, when starting from the efficient steady state, the consumption level of Home and Foreign type s households are always identical as they face the same risk-free interest rate and price level.

4.4.1 Optimal monetary policy in a simplified model

We consider optimal policy under commitment from a “timeless perspective” as defined in Woodford (2003) chapter 7. Optimal monetary policy is determined by minimizing the theoretical loss function (4.12) subject to the equilibrium with the 14 endogenous variables

¹⁷See for example Benigno (2004) for a welfare-loss function derived for a currency union with different level of nominal rigidity.

4.4. Optimal monetary policy

pinned down by the equations outlined in the previous section.

Given the model complexity, solving for optimal monetary policy is rather involved. To yield analytical solutions and to gain insights into the implication of the sovereign risk spillover for optimal monetary policy, some simplifying assumptions are indispensable. In the following, I derive the optimal target criterion for a simplified version of the model and focus on the more realistic case with long-term government bonds. This “approximated” target criterion helps to illustrate tradeoffs facing the central bank as a result of the spillover. It also indicates beneficial adjustments to the monetary policy. Afterwards, I proceed to numerically investigate optimal monetary policy in the full model.

The simplified model has to be plain enough to cede insights analytically but still reflects the role of sovereign risk spillover on model dynamics. Here, I rely on the following simplifying assumptions. First, following Corsetti et al. (2014), it is assumed that terms of trade remain constant and the private sector spreads do not enter the union-wide Phillips curve.¹⁸ Secondly, the private sector spreads are posited to be functions of local deficits and inflation. This reflects the role of deficits and inflation on sovereign indebtedness but ignores the direct effect of the risk-free rate, which is small at reasonable maturity. The credit spreads are thus determined as

$$\begin{aligned}\hat{\omega}_t &= -\tilde{\Phi}_\pi \hat{\Pi}_t - \tilde{\Phi}_y (\phi_{T,y} \hat{y}_t - \tilde{g}_t) + s_t, \text{ and} \\ \hat{\omega}_t^* &= -\tilde{\Phi}_\pi^* \hat{\Pi}_t - \tilde{\Phi}_y^* (\phi_{T,y}^* \hat{y}_t^* - \tilde{g}_t^*) + s_t^*.\end{aligned}$$

All four parameters $\tilde{\Phi}_\pi$, $\tilde{\Phi}_\pi^*$, $\tilde{\Phi}_y$, $\tilde{\Phi}_y^*$ are positive and are crucial in capturing the role of sovereign risk on the economy. The more susceptible the private sector credit frictions are to variations in the deficits and inflation, the larger these parameters. Finally, to reflect the impact of spreads on the distributional inefficiency (see (4.2) and (4.5)), it is assumed that

$$\begin{aligned}\bar{\lambda}_{R,t} &= -\tilde{\Phi}_\lambda \bar{\omega}_t, \text{ and} \\ \hat{\lambda}_{R,t}^D &= -\tilde{\Phi}_\lambda^D \hat{\omega}_t^D,\end{aligned}$$

with $\tilde{\Phi}_\lambda$ and $\tilde{\Phi}_\lambda^D$ both positive and reflects how much distributional inefficiency is caused by the private sector credit spreads.

Under these assumption, one can derive a (relatively) simple form of the optimal target

¹⁸This can be achieved, for example, through the introduction of labor subsidies/taxes.

4.4. Optimal monetary policy

criterion:¹⁹

$$\begin{aligned}
 & \mu \hat{\Pi}_t + \Delta \bar{x}_t \\
 & - \Omega \tilde{\Phi}_\lambda \left[\left(\tilde{\Phi}_y + \kappa \tilde{\Phi}_\pi \right) \bar{\omega}_t - \tilde{\Phi}_y \bar{\omega}_{t-1} \right] \\
 & - \Omega^D \tilde{\Phi}_\lambda^D \left[\left(\tilde{\Phi}_y^D + \kappa \tilde{\Phi}_\pi^D \right) \hat{\omega}_t^D - \tilde{\Phi}_y^D \hat{\omega}_{t-1}^D \right] = 0
 \end{aligned} \tag{4.13}$$

The ‘simplified’ optimal target criterion lays out the relationship between inflation, output gap and private sector spread that the central bank should seek to maintain at all time. Not surprisingly, absent variations in the private sector spread – or if credit spreads are exogenous and thus independent of monetary policy, the optimal target criterion reduces to one as in the basic NK model (first line of the target criterion).

With endogenous private sector spreads, the central bank can now influence also the distributional inefficiency between savers and borrowers households - both on the union-level and across regions. In particular, higher output and/or inflation should be tolerated as this helps to reduce government default risk and in turns enhance the distributional efficiency (the second line of the optimal target criterion). Given a level of average spread, the more important the distributional inefficiency is for welfare (large Ω), or the more effective output (large $\tilde{\Phi}_y$) and inflation (large $\tilde{\Phi}_\pi$) in reducing credit spreads, the higher output and inflation should be targeted.

In a currency union with asymmetrical sovereign debt level, the distributional inefficiency across region is also within the influence of the central bank (last line of the target criterion). Specifically, more inflation and output should be generated if the private sector spread is higher in the region with a stronger influence of sovereign default risk as reflected in $\tilde{\Phi}_y$ and $\tilde{\Phi}_\pi$.²⁰

The result above indicates that augmenting the simple target criterion with reaction to union-wide average spread and the wedge between regional spreads may bring the monetary policy closer to optimal. In the following, I will examine whether this result holds (approximately) in the general setup.

¹⁹See Appendix 4.A.6 for the derivation .

²⁰The target criterion can also be written in terms of ‘weighted’ average of spreads: $\mu \hat{\Pi}_t + \Delta \bar{x}_t - (\varpi \Delta \hat{\omega}_t + \varpi^* \Delta \hat{\omega}_t^*) - (\zeta \hat{\omega}_t + \zeta^* \hat{\omega}_t^*) = 0$, where $\varpi > \varpi^*$ and $\zeta > \zeta^*$ the overall degree of sovereign risk spillover is stronger in Home.

4.4. Optimal monetary policy

4.4.2 Numerical analysis

Figures 4.5 - 4.7 compare the model dynamics to various shocks under four monetary policies: (1) the Taylor rule as described in the previous section, labeled as ‘Taylor’; (2) the numerically derived optimal policy under timeless perspective, labeled as ‘Optimal’;²¹ (3) the ‘simplified optimal target criterion’ (4.13), labeled as ‘AdjTarget’ ; (4) a basic target criterion that is the first line of the ‘simplified optimal target criterion’, labeled as ‘Target’.

The adjusted target criterion is calibrated with the following coefficients. These coefficients are combinations of structural parameters, and the calibration aims to reflect the microfounded full model. The rationale for the parameterization is provided in Appendix 4.A.7.

$$7.667 \hat{\Pi}_t + \Delta \bar{x}_t - 0.045 \bar{\omega}_t + 0.041 \bar{\omega}_{t-1} + 0.019 \hat{\omega}_t^D - 0.018 \hat{\omega}_{t-1}^D = 0$$

To examine the impact asymmetric debt level, it is assumed that the exogenous shocks hit only the Foreign region and the size of the shock is fixed at a level so that the union-wide average shock corresponds to the shock size analyzed in the previous section.

Figure 4.5 shows the equilibrium responses of the endogenous variables to a cost-push shock in Foreign (u^*). As seen before under the Taylor rule, this kind of shock invokes a limited reaction in government debt and thus has a small impact on private sector spreads. Since the shock’s impact on distributional inefficiency is negligible, the simple target rule is closed to optimal. Indeed, both the model dynamics under optimal policy is indistinguishable from that under the two versions of target criterion. The equilibrium associated with the Taylor rule is, however, lies far from the one under optimal policy.²²

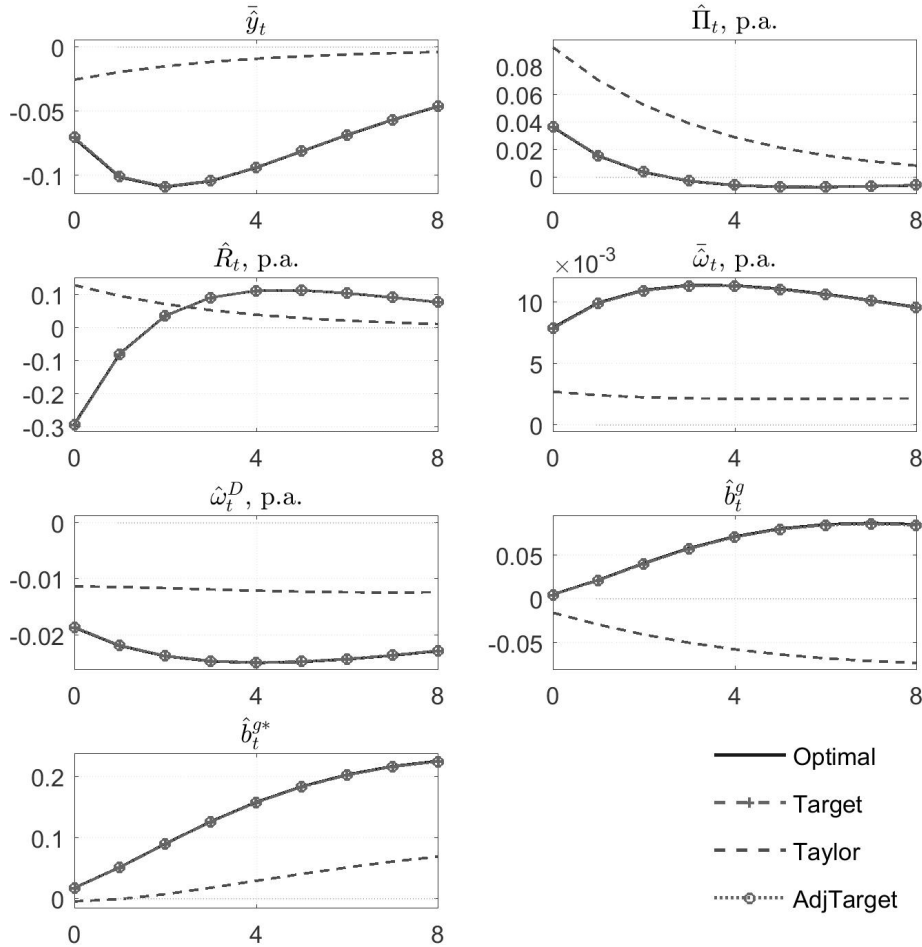
As discussed in the previous section, the sovereign risk spillover has a more pronounced impact on the transmission of shocks directly affecting the government financing. One can thus expect that optimal policy responses are more influenced by the spillover for such shocks. Figure 4.6 shows the impulse responses to a sovereign default probability shock. When facing the default probability shock in Foreign, the Foreign government indebtedness increases, leading to a notable increase in the Foreign private sector spreads while private sector spread in Home barely moves (not shown). As a result, the private sector spread in

²¹More specifically, first-order conditions are derived by maximizing the union welfare function (4.11) subject to the constraints as detailed in Appendix 4.A.1. The resulting system of nonlinear equations is log-linearized around the efficient steady state and solved for the model equilibrium.

²²This is mainly because the Taylor rule is not optimal for this kind of disturbances already under a simple NK model, and not because of the sovereign risk spillover.

4.4. Optimal monetary policy

Figure 4.5: Impulse responses under alternative monetary policies: cost-push shock

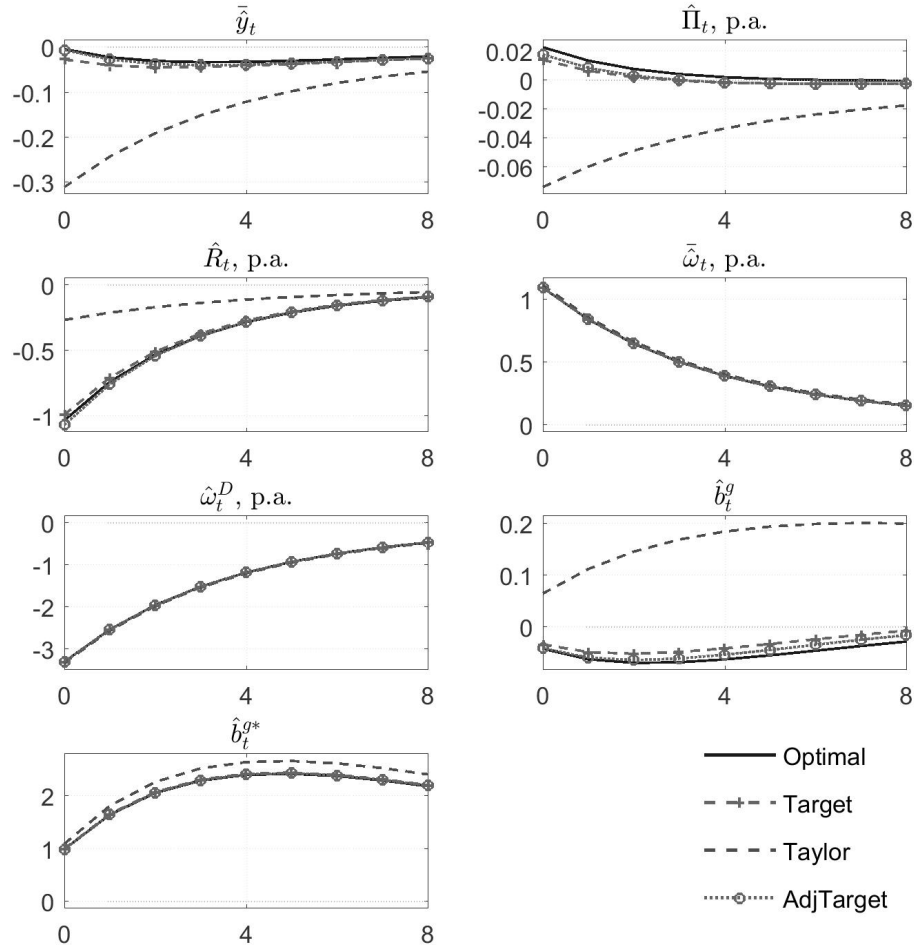


Impulse response of endogenous model variables to $1/(1-\theta)\%$ Foreign cost-push shock (u^*). Variables are plotted as percentage point derivation from the steady state. p.a. = annualized.

Foreign is initially around 300 basis points (annualized) above that in Home. The default probability shock leads to a distributional inefficiency between Home and Foreign, and under the sovereign risk spillover, this requires the central bank to generate positive output and inflation more than prescribed by the simple target criterion. The adjusted target criterion, by reacting to the private sector spreads, does bring the equilibrium somewhat

4.4. Optimal monetary policy

Figure 4.6: Impulse responses under alternative monetary policies:
default probability shock



Impulse response of endogenous model variables to a default probability shock that increases Foreign sovereign default probability by $1/(1 - \theta)$ percentage points initially (ϵ^{P^*}). Variable are plotted as percentage point derivation from the steady state. p.a. = annualized.

closer to the optimal. But as the equilibrium under simple target criterion is already not far from the one under optimal policy, the improvement through using the adjusted target criterion is limited. As in the case of the cost-push shock, the simple Taylor rule is again

4.4. Optimal monetary policy

far from optimal.

With the examples of the two types of disturbances described above, we see that under a realistic calibration, the simple target rule provides a reasonable approximation to optimal policy under the sovereign risk spillover. The target rule that is augmented with reactions to private sector spreads (4.13) presents an equilibrium closer to the optimal but the implementation is much more complex, and the room for improvement is limited. These results are not limited to the two types of shocks analyzed here, and the impulse responses for a variety of other shocks are provided in Appendix 4.A.9.

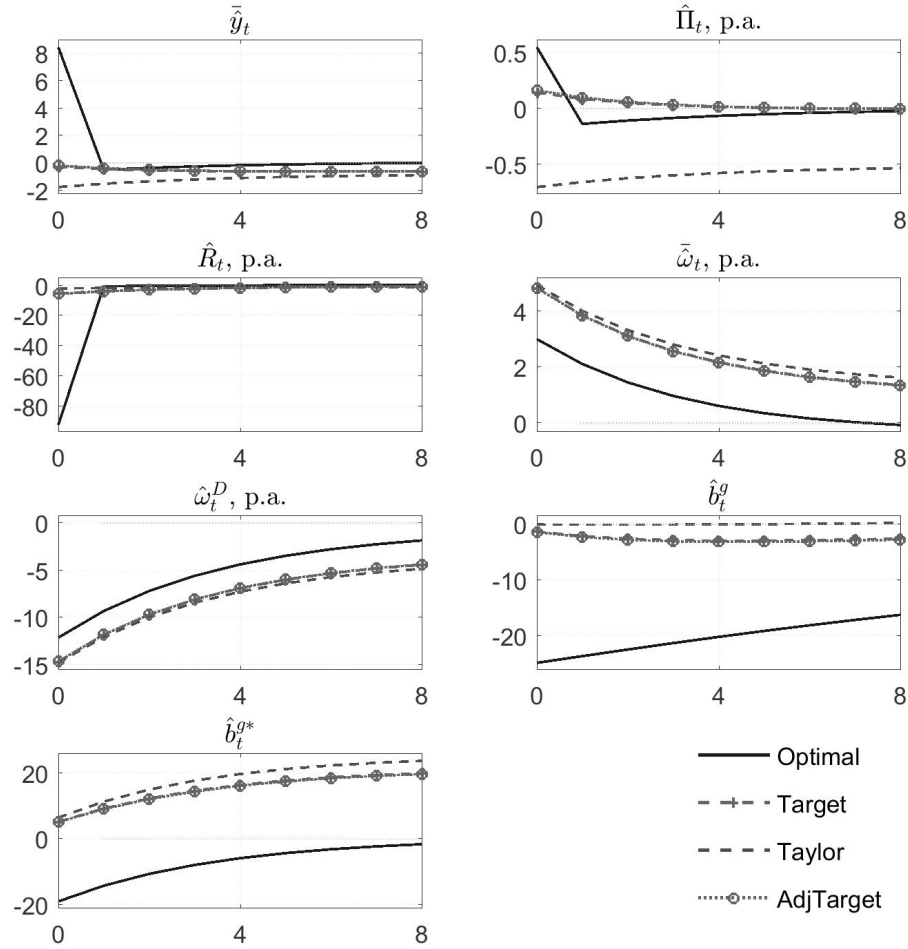
What about the case when the government debt is short-term? We have already seen that the maturity structure of the government debt has a non-negligible role on the impact of sovereign risk spillover. How does optimal policy differ for long-term and short-term government debt? Figure 4.7 answers this question with impulse responses to a default probability in Foreign when the government debts in both regions are calibrated to be one-period.²³ Now with short-term debt, a drop in the risk-free rate becomes very effective in reducing the government indebtedness. As the government debt only evolves period-by-period, an initial drop in the government indebtedness results in a below average steady state level for a protracted period, which helps to counteract the effect of the default probability shock. Optimal monetary policy makes use of this and features a strong drop in the period when the shock hits. Afterwards, optimal monetary policy resembles that under a simple target criterion and the adjusted target criterion. Comparing the debt level under the case ‘Target’ to that under optimal policy, one can see that thanks to the initial large drop in \hat{R}_t , the debt level under optimal monetary policy stay low for a long time. The large initial deviation of output and inflation is compensated by the persistently less distributional inefficiency as reflected in $\bar{\lambda}_{R,t}$ and $\hat{\lambda}_{R,t}^D$.²⁴

²³All other parameters that are not targeted are kept at the baseline calibration. Parameters that are used to target steady state statistics are re-calibrated. The coefficients in the adjusted target criterion are also updated with the short-maturity.

²⁴The large initial changes in optimal monetary policy are not limited to the default probability but is a general feature of optimal monetary policy when the government bond is short-term.

4.4. Optimal monetary policy

Figure 4.7: Impulse responses under alternative monetary policies and short-term government debt: default probability shock



Impulse response of endogenous model variables in a model calibrated with one-period government debt to a default probability shock that increases Foreign sovereign default probability by $1/(1 - \theta)$ percentage points initially (ϵ^{p*}). Variable are plotted as percentage point derivation from the steady state. p.a. = annualized.

4.5 Conclusion

The euro area debt crisis has seen a strong linkage between sovereign debt default risk and the private-sector financing condition. In this paper, I examine the implication of sovereign risk spillover for monetary policy in a currency union.

The maturity structure is crucial for the impact of the sovereign risk spillover on shock propagation and optimal policy. When calibrated to the euro area and taken into account the average long maturity of government debt, the impact of the sovereign risk spillover on shock transmission is limited for a variety of shocks.

With the sovereign risk spillover, optimal monetary policy involves striking the right balance between output, inflation, distributional inefficiency between savers and borrowers and across regions. However, for the euro area, a simple target criterion that describes the optimal relation between output and inflation as derived from a basic New Keynesian model continues to provide a reasonable approximation to optimal policy.

4.A Appendix

4.A.1 Nonlinear structural equations

This section provides the nonlinear system of equations for Home and those on the union-level. The equations for Foreign follow analogously.

Households:

$$q_t = \beta \mathbb{E}_t \left\{ \frac{\delta \lambda_{s,t+1} + (1 - \delta) \bar{\lambda}_{t+1}}{\lambda_{s,t} \Pi_{t+1}} \right\} \quad (4.A.1)$$

$$q_t^g = \beta \mathbb{E}_t \left\{ (1 - \vartheta \mathbf{p}_{t+1}) \left[\eta + (1 - \eta)(r + q_{t+1}^g) \right] \frac{\delta \lambda_{s,t+1} + (1 - \delta) \bar{\lambda}_{t+1}}{\lambda_{s,t} \Pi_{t+1}} \right\} \quad (4.A.2)$$

$$q_t^b = \beta \mathbb{E}_t \left\{ \frac{\delta \lambda_{b,t+1} + (1 - \delta) \bar{\lambda}_{t+1}}{\lambda_{b,t} \Pi_{t+1}} \right\} \quad (4.A.3)$$

$$q_t^{g,rf} = \beta \mathbb{E}_t \left\{ \left[\eta + (1 - \eta)(r + q_{t+1}^{g,rf}) \right] \frac{\delta \lambda_{s,t+1} + (1 - \delta) \bar{\lambda}_{t+1}}{\lambda_{s,t} \Pi_{t+1}} \right\} \quad (4.A.4)$$

$$c_{s,t} = \left(\frac{\xi_s}{\lambda_{s,t}} \right)^{1/\sigma} \quad (4.A.5)$$

$$c_{b,t} = \left(\frac{\xi_b}{\lambda_{b,t}} \right)^{1/\sigma} \quad (4.A.6)$$

$$h_{s,t}^v = \frac{\lambda_{s,t} w_t}{\psi_s} \quad (4.A.7)$$

$$h_{b,t}^v = \frac{\lambda_{b,t} w_t}{\psi_b} \quad (4.A.8)$$

$$q_t^g = \frac{\eta + (1 - \eta) r}{R_t^g - (1 - \eta)} \quad (4.A.9)$$

$$1 + \omega_t = \chi^\psi (\omega_t^g)^{\alpha^\psi} \exp(st) \quad (4.A.10)$$

$$1 + \omega_t = \frac{q_t}{q_t^b} \quad (4.A.11)$$

4.A. Appendix

Assets:

$$A_t^\dagger = \theta \frac{b_{t-1}^g}{\Pi_t} [(1-\eta) q_t^g + \eta + (1-\eta) r] \quad (4.A.12)$$

$$+(1-\theta) \left(\frac{b_t^{g*}}{\Pi_t} \right) [(1-\eta^*) q_t^{g*} + \eta^* + (1-\eta^*) r^*]$$

$$b_t q_t^b = \delta \frac{b_{t-1}^b}{\Pi_t} + \pi_b \left[c_{b,t} - w_t h_{b,t} - \frac{P_{H,t}}{P_t} y_{H,t} + w_t h_t \right] \quad (4.A.13)$$

$$-(\theta(s_t q_t - b_t q_t^b) + (1-\theta)(s_t^* q_t - b_t^* q_t^{b*}))$$

$$+t^g + \phi_{T,y} y_t + \phi_{T,b^g} \frac{b_{t-1}^g}{\Pi_t} \Big] - \pi_b (1-\delta) A_t^\dagger$$

$$s_t q_t + b_t^g q_t^g = \delta \left(\frac{s_{t-1}}{\Pi_t} + \frac{b_{t-1}^g}{\Pi_t} [(1-\eta) q_t^g + \eta + (1-\eta) r] \right) \quad (4.A.14)$$

$$-\pi_s \left[c_{s,t} - w_t h_{s,t} - \frac{P_{H,t}}{P_t} y_{H,t} + w_t h_t \right]$$

$$-(\theta(s_t q_t - b_t q_t^b) + (1-\theta)(s_t^* q_t - b_t^* q_t^{b*}))$$

$$+t^g + \phi_{T,y} y_t + \phi_{T,b^g} \frac{b_{t-1}^g}{\Pi_t} \Big] + \pi_s (1-\delta) A_t^\dagger$$

Firms:

$$F_t = K_t \quad (4.A.15)$$

$$F_t = \lambda_t y_t \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{1-\mu} + \alpha \beta \mathbb{E}_t \left(\frac{P_{H,t}^{opt} \Pi}{P_{H,t+1}^{opt}} \right)^{1-\mu} F_{t+1} \quad (4.A.16)$$

$$K_t = \lambda_t \frac{\mu}{\mu-1} \mathcal{M} w_t \frac{y_t}{z_t} \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{-\mu} \frac{P_t}{P_{H,t}} + \alpha \beta \mathbb{E}_t \left(\frac{P_{H,t}^{opt} \Pi}{P_{H,t+1}^{opt}} \right)^{-\mu} K_{t+1} \quad (4.A.17)$$

$$1 - \alpha \left(\frac{\Pi}{\Pi_{H,t}} \right)^{1-\mu} = (1-\alpha) \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{1-\mu} \quad (4.A.18)$$

$$\Delta_{H,t} = \alpha \Delta_{H,t-1} \left(\frac{\Pi_{H,t}}{\Pi} \right)^\mu + (1-\alpha) \left(\frac{P_{H,t}^{opt}}{P_{H,t}} \right)^{-\mu} \quad (4.A.19)$$

$$\tau_t = \frac{P_{H,t}}{P_{F,t}} \quad (4.A.20)$$

4.A. Appendix

Government budget constraint and default risk:

$$\left[b_t^g - (1 - \eta) \frac{b_{t-1}^g}{\Pi_t} \right] q_t^g = [\eta + (1 - \eta)r] \frac{b_{t-1}^g}{\Pi_t} + g_t - \left(t^g + \phi_{t,y} y_t + \phi_{T,b^g} \frac{b_{t-1}^g}{\Pi_t} \right) \quad (4.A.21)$$

$$p_{t+1} = F_{beta} \left(\frac{b_t^g}{4y_H} \frac{1}{b_{g,max}}; \alpha_{b^g}, \beta_{b^g} \right) \quad (4.A.22)$$

$$\omega_t^g = \frac{R_t^g}{R_t^{g,r,f}} \quad (4.A.23)$$

Market clearing conditions:

$$y_t \Delta_{H,t} = z_t h_t \quad (4.A.24)$$

$$h_t = \pi_s h_{s,t} + \pi_b h_{b,t} \quad (4.A.25)$$

$$y_t = \left(\frac{P_{H,t}}{P_t} \right)^{-1} \left[\theta (c_t + g) + (1 - \theta)(c_t^* + g^*) \right] \quad (4.A.26)$$

$$\theta s_t + (1 - \theta)s_t^* = \theta b_t + (1 - \theta)b_t^* \quad (4.A.27)$$

Definitions:

$$\Delta_{H,t} = \frac{1}{\theta} \int_0^\theta \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\mu} dj$$

4.A.2 Efficient allocation

This section describes the efficient allocation. The efficient allocation is the solution to a social planner's problem of maximizing (4.11), subject to the technological and resource constraints. Here, I assume that the social planner has the same Pareto weights as the central bank. Because of the linear production technology, I assume symmetric equilibrium, i.e. $y_{H,t}(j) = y_{H,t}$ and $y_{F,t}(j) = y_{F,t}$.

4.A. Appendix

Each period, social planner's problem is described by the following Lagrangian:

$$\begin{aligned}
 \mathbf{L} = & \theta(\pi_s u_{s,t} + \pi_b u_{b,t}) + (1 - \theta)(\pi_s u_{s,t}^* + \pi_b u_{b,t}^*) \\
 & + \mu_1 [\theta(\pi_s c_{s,t} + \pi_b c_{b,t}) + (1 - \theta)(\pi_s c_{s,t}^* + \pi_b c_{b,t}^*) - \bar{y}_t] \\
 & + \mu_2 (y_t^\theta y_t^{*1-\theta} - \bar{y}_t) \\
 & + \mu_3 [z(\pi_s h_{s,t} + \pi_b h_{b,t}) - y_t] \\
 & + \mu_4 [z(\pi_s h_{s,t}^* + \pi_b h_{b,t}^*) - y_t^*]
 \end{aligned}$$

It is easier to show that the efficient allocation features equalized marginal utility of consumption across all four types of households: $\lambda_{s,t} = \lambda_{b,t} = \lambda_{s,t}^* = \lambda_{b,t}^*$. Given the utility functions, it implies that $c_{s,t} = c_{s,t}^*$, $c_{b,t} = c_{b,t}^*$ and $c_{b,t} = c_{s,t}(\xi_b/\xi_s)^{1/\sigma}$. On the labor side, the marginal utility of labor are also equalized, thus we have $h_{s,t} = h_{s,t}^*$, $h_{b,t} = h_{b,t}^*$, $h_{b,t} = h_{s,t}(\psi_s/\psi_b)^{1/v}$. As a result, per capita output in both countries are the same $y_t = y_t^*$. The marginal utility of consumption equals the marginal utility of labor, so we also have $c_{\tau,t} = \left(\frac{\xi_\tau z}{\psi_\tau h_{\tau,t}^v}\right)^{1/\sigma}$. Finally, Home saver household's labor supply is pinned down by

$$\left(\frac{\xi_s z_t}{\psi_s h_{s,t}^v}\right)^{1/\sigma} \left(\pi_s + \pi_b \left(\frac{\xi_b}{\xi_s}\right)^{1/\sigma}\right) = z h_{s,t} \left(\pi_s + \pi_b \left(\frac{\psi_s}{\psi_b}\right)^{1/v}\right)$$

As shown below, a steady state with zero interest rate spread between savers and borrowers is efficient.

4.A.3 Steady state

This section describes the steady state of the model. Variables without a time index refer to the steady state value unless otherwise noted. Public indebtedness and private sector asset/debt holdings may differ across countries. Otherwise, the regions are assumed to be symmetric. Furthermore, the price level within a country is assumed to be uniform, i.e., $P_H(j) = P_H$ and $P_F(j) = P_F$.

From the savers' Euler equations, it is obvious that $\lambda_{s,t} = \lambda_{s,t}^* \forall t$. So this is also valid in steady state. Given ω and ω^* , the following three Euler equations together determine q ,

4.A. Appendix

$\lambda_R = \lambda_s/\lambda_b$ as well as $\lambda_{b,R} = \lambda_b^*/\lambda_b$

$$\begin{aligned}\lambda_R &= \frac{\beta}{q\Pi} [\delta\lambda_R + (1-\delta)\pi_s\lambda_R + (1-\delta)\pi_b(\theta + (1-\theta)\lambda_{b,R})] \\ 1 &= \frac{\beta(1+\omega)}{q\Pi} [\delta + (1-\delta)\pi_s\lambda_R + (1-\delta)\pi_b(\theta + (1-\theta)\lambda_{b,R})] \\ \lambda_{b,R} &= \frac{\beta R^d(1+\omega^*)}{q\Pi} [\delta\lambda_{b,R} + (1-\delta)\pi_s\lambda_R + (1-\delta)\pi_b(\theta + (1-\theta)\lambda_{b,R})]\end{aligned}$$

In steady state, the relative marginal utility is related to terms of trade by

$$\tau^{1+1/v} = \frac{\pi_s(\lambda_R/\psi_R)^{1/v} + \pi_b(\lambda_{b,R})^{1/v}}{\pi_s(\lambda_R/\psi_R)^{1/v} + \pi_b}.$$

steady state real wage $w = z$ and labor supplies satisfy

$$h_s = h_b(\lambda_R/\psi_R)^{1/v}, \quad h_s^* = h_b(\lambda_R/(\psi_R\tau))^{1/v}, \quad h_b^* = h_b(\lambda_{b,R}/\tau)^{1/v},$$

$$1 = zh_b \left[\pi_s(\lambda_R/\psi_R)^{1/v} + \pi_b \right], \text{ and}$$

$$\lambda_s z = \psi_s h_s^v, \quad \lambda_b z = \psi_b h_b^v.$$

On the consumption side, the steady state requires

$$c_s = c_b(\lambda_R/\xi_R)^{-1/\sigma}, \quad c_s^* = c_s, \quad c_b^* = c_b(\lambda_{b,R})^{-1/\sigma},$$

$$1 = \tau^{-1+\theta} c_b \left[\pi_s(\lambda_R/\xi_R)^{-1/\sigma} + \theta\pi_b + (1-\theta)\pi_b(\lambda_{b,R})^{-1/\sigma} \right],$$

$$c_s = \left(\frac{\xi_s}{\lambda_s} \right)^{1/\sigma}, \quad c_b = \left(\frac{\xi_b}{\lambda_b} \right)^{1/\sigma}, \text{ and}$$

$$\pi_s c_s + \pi_b c_b = y.$$

For zero steady state credit spread, we have $c_b = c_b^*$ and $\tau = 1$. The interests rate is $1/(q\Pi) = 1/((1+w)q^b\Pi) = 1/\beta$ and the relative marginal utility $\lambda_R = 1$. This steady state satisfies the conditions for an efficient allocation derived above.

4.A. Appendix

4.A.4 Approximate equilibrium

In this section, I derive the log-linearized model by taking a *first-order* Taylor expansion of the nonlinear equations around the efficient steady state with zero credit spreads. $\hat{x}_t = \log \frac{x_t}{x}$ denotes the log-derivation of variable x_t from its steady state value x . To save on notation, I drop the terms representing approximation errors of second or higher orders $\vartheta(\|\Xi\|^2)$.

A first-order approximation to Home Euler equations yields the IS relations

$$\begin{aligned}\hat{\lambda}_{s,t} &= \hat{R}_t^d - \mathbb{E}_t \hat{\Pi}_{t+1} + \delta \mathbb{E}_t \hat{\lambda}_{s,t+1} + (1 - \delta) \mathbb{E}_t \hat{\lambda}_{t+1}, \\ \hat{\lambda}_{b,t} &= \hat{R}_t^d + \hat{\omega}_t - \mathbb{E}_t \hat{\Pi}_{t+1} + \delta \mathbb{E}_t \hat{\lambda}_{b,t+1} + (1 - \delta) \mathbb{E}_t \hat{\lambda}_{t+1},\end{aligned}$$

with $\bar{\lambda}_t = \theta(\pi_b \hat{\lambda}_{s,t} + \pi_s \hat{\lambda}_{s,t}) + (1 - \theta)(\pi_b \hat{\lambda}_{b,t}^* + \pi_s \hat{\lambda}_{s,t}^*)$. Similar equations can be derived for Foreign households. Aggregating over the four types of household, we arrive at

$$\hat{\lambda}_t = \hat{R}_t^d + \pi_b \bar{\omega}_t - \mathbb{E}_t \hat{\Pi}_{t+1} + \mathbb{E}_t \hat{\lambda}_{t+1},$$

with $\bar{\omega}_t = \theta \hat{\omega}_t + (1 - \theta) \hat{\omega}_t^*$. Using the definition of $\bar{\lambda}_{R,t} = \theta \hat{\lambda}_{R,t} + (1 - \theta) \hat{\lambda}_{R,t}^*$, and $\hat{\lambda}_{R,t}^D = \hat{\lambda}_{R,t} - \hat{\lambda}_{R,t}^*$, we have

$$\bar{\lambda}_{R,t} = -\bar{\omega}_t + \delta \mathbb{E}_t \bar{\lambda}_{R,t+1}, \quad (4.A.28)$$

$$\hat{\lambda}_{R,t}^D = -\hat{\omega}_t^D + \delta \mathbb{E}_t \hat{\lambda}_{R,t+1}^D. \quad (4.A.29)$$

with $\bar{\omega}_t = \theta \log [(1 + \omega_t)/(1 + \omega)] + (1 - \theta) \log [(1 + \omega_t^*)/(1 + \omega^*)]$ and $\hat{\omega}_t^D = \hat{\omega}_t - \hat{\omega}_t^*$.

A first-order approximation to the goods market clearing condition yields:

$$\bar{y}_t - \bar{g}_t = \theta \pi_s c_s \hat{c}_{s,t} + \theta \pi_b c_b \hat{c}_{b,t} + (1 - \theta) \pi_s c_s \hat{c}_{s,t}^* + (1 - \theta) \pi_b c_b \hat{c}_{b,t}^*$$

where $\bar{g}_t = \theta g_t + (1 - \theta) g_t^*$ and g_t, g_t^* are the government spending shocks. Define parameter $S_\lambda = \pi_s \pi_b (c_s - c_b)$. Using the above relation as well as $\hat{\lambda}_{\tau,t} = -\sigma_\tau \hat{c}_{\tau,t}$, we have

$$\bar{\lambda}_t = -\sigma (\bar{y}_t - \bar{g}_t) - S_\lambda \bar{\lambda}_{R,t}.$$

Thus, the aggregated IS-curve is

$$\bar{y}_t = \mathbb{E}_t \bar{y}_{t+1} - \mathbb{E}_t \Delta \bar{g}_{t+1} - \frac{1}{\sigma} \left[-\hat{q}_t + (\pi_b - S_\lambda) \bar{\omega}_t - \mathbb{E}_t \hat{\Pi}_{t+1} - S_\lambda (1 - \delta) \mathbb{E}_t \bar{\lambda}_{R,t+1} \right] \quad (4.A.30)$$

4.A. Appendix

The derivation of the country-level Phillips curve is similar to that in a textbook NK model. For Home, we have

$$\hat{\Pi}_{H,t} = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha} (\hat{w}_t - \hat{z}_t - (1-\theta)\hat{\tau}_t) + \beta \mathbb{E}_t \hat{\Pi}_{H,t+1}.$$

Labor market clearing conditions imply

$$\hat{w}_t = v\hat{y}_t - v\hat{z}_t - z\hat{V}_t$$

with $\hat{V}_t = \pi_b h_b \hat{\lambda}_{b,t} + \pi_s h_s \hat{\lambda}_{s,t}$. The Home Phillips curve can then be rewritten as

$$\hat{\Pi}_{H,t} = \beta \mathbb{E}_t \hat{\Pi}_{H,t+1} + \mathsf{K} \left[v\hat{y}_t - (v+1)\hat{z}_t - z\hat{V}_t - (1-\theta)\hat{\tau}_t \right],$$

with $\mathsf{K} = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}$. Analogously, the Foreign Phillips curve is

$$\hat{\Pi}_{F,t} = \beta \mathbb{E}_t \hat{\Pi}_{F,t+1} + \mathsf{K} [v\hat{y}_t^* - (v+1)\hat{z}_t^* - z\hat{V}_t^* + \theta\hat{\tau}_t].$$

Next step, using the relation

$$z\theta\hat{V}_t + z(1-\theta)\hat{V}_t^* = -\sigma\bar{y}_t - \left(S_\lambda + \pi_s \left(1 - \frac{h_s}{h}\right) \right) \bar{\lambda}_{R,t} + \sigma\bar{g}_t,$$

we have the area-wide Phillips curve:

$$\hat{\Pi}_t = \beta \mathbb{E}_t \hat{\Pi}_{t+1} + \mathsf{K} \left[(v+\sigma)\bar{y}_t + [S_\lambda + \pi_s(1 - h_s/h)] \bar{\lambda}_{R,t} - (v+1)\bar{z}_t - \sigma\bar{g}_t \right].$$

Or

$$\hat{\Pi}_t = \beta \mathbb{E}_t \hat{\Pi}_{t+1} + \kappa \bar{x}_t + \kappa_\lambda \bar{\lambda}_{R,t} \tag{4.A.31}$$

where $\bar{x}_t = \theta x_t + (1-\theta)x_t^*$ is the union-wide average deviation of the actual output from the efficient output. For each region, this output gap is defined as

$$\begin{aligned} x_t &= \hat{y}_t - \hat{y}_t^e, & x_t^* &= \hat{y}_t^* - \hat{y}_t^{e*} \\ \hat{y}_t^e &= \frac{1}{v+\sigma} \left((v+1)\hat{z}_t + \sigma\bar{g}_t \right), & \hat{y}_t^{e*} &= \frac{1}{v+\sigma} \left((v+1)\hat{z}_t^* + \sigma\bar{g}_t \right). \end{aligned}$$

Define $\kappa = \mathsf{K}(v+\sigma)$, $\kappa_\lambda = \mathsf{K}[S_\lambda + \pi_s(1 - h_s/h)]$. The law of motion for terms of trade is derived by taking difference between the two regions' Philips curves. We have

$$\Delta\hat{\tau}_t = \beta \mathbb{E}_t \Delta\hat{\tau}_{t+1} + \mathsf{K} \left[-(v+1)\hat{\tau}_t + z\pi_b h_b \hat{\lambda}_{R,t}^D - (v+1)\hat{z}_t^D \right]. \tag{4.A.32}$$

4.A. Appendix

Turning to the public sector, the government debt level evolves according to

$$\hat{b}_t^g = \chi_g \hat{b}_{t-1}^g - \chi_g \hat{\Pi}_t - \frac{\phi_{T,y}}{b^g q^g} \hat{y}_t - \left(1 - \frac{1-\eta}{\Pi}\right) \hat{q}_t^g \quad (4.A.33)$$

with $\chi_g = [\eta + (1-\eta)(r+q^g) - \phi_{T,b^g}]/(\Pi q^g)$. Using the Euler equations, we can show that government bond prices depend on the price of the risk-free deposit, the government debt level as well as expected future price:

$$\hat{q}_t^g = \hat{q}_t - \frac{\vartheta \mathbf{p}}{1-\vartheta \mathbf{p}} F'_{beta} \frac{b^g}{\mathbf{p}} \mathbb{E}_t \hat{b}_{t+1}^g + \frac{(1-\eta)q^g}{\eta + (1-\eta)(r+q^g)} \mathbb{E}_t \hat{q}_{t+1}^g, \quad (4.A.34)$$

where F'_{beta} is the first derivative of the equation (4.A.22) with respect to government debt, evaluated at its steady state value. The definition of government bond spreads gives us

$$\hat{\omega}_t^g = -[1 - (1-\eta)q(1-\vartheta \mathbf{p})] \hat{q}_t^g + [1 - (1-\eta)q] \hat{q}_t^{g,rf}.$$

Using the Euler equations again, the above equation can be rewritten as

$$\begin{aligned} \hat{\omega}_t^g &= (1-\eta)q \mathbb{E}_t \hat{\omega}_{t+1}^g + \chi \vartheta \mathbf{p} (1-\eta)q \mathbb{E}_t \hat{q}_{t+1}^g \\ &\quad - (1-\eta)q \vartheta \mathbf{p} \hat{q}_t + \chi \frac{\vartheta \mathbf{p}}{1-\vartheta \mathbf{p}} F'_{beta} \frac{b^g}{\mathbf{p}} \mathbb{E}_t \hat{b}_{t+1}^g \end{aligned} \quad (4.A.35)$$

where $\chi = [1 - (1-\eta)q(1-\vartheta \mathbf{p})]$. Finally, with the sovereign risk spillover, the private sector spreads (average and difference) are functions of the private sector credit spreads:

$$\bar{\hat{\omega}}_t = \alpha_\psi [\theta \hat{\omega}_t^g + (1-\theta) \hat{\omega}_t^{g*}] + \bar{s}_t, \quad (4.A.36)$$

$$\hat{\omega}_t^D = \alpha_\psi (\hat{\omega}_t^g - \hat{\omega}_t^{g*}) + s_t^D, \quad (4.A.37)$$

4.A.5 Welfare function

This section provides the derivation of the second-order approximated welfare function. $\vartheta(\|\Xi\|^2)$ represents approximation errors of second or higher order, $\vartheta(\|\Xi\|^3)$ are approximation errors of third or higher order. *t.i.p.* stands for terms independent of policy.

The objective function for the central bank for period t is

$$E_0 \sum_{t=0}^{\infty} \beta^t U_t$$

with $U_t = U_t^{(1)} - U_t^{(2)}$, $U_t^{(1)} = \theta[\pi_s \tilde{u}_{s,t} + \pi_b \tilde{u}_{b,t}] + (1-\theta)[\pi_s \tilde{u}_{s,t}^* + \pi_b \tilde{u}_{b,t}^*]$, $U_t^{(2)} =$

4.A. Appendix

$\theta[\pi_s \tilde{v}_{s,t} + \pi_b \tilde{v}_{b,t}] + (1 - \theta)[\pi_s \tilde{v}_{s,t}^* + \pi_b \tilde{v}_{b,t}^*]$, $\tilde{u}_{\tau,t} = \frac{\xi_\tau c_{\tau,t}^{1-\sigma}}{1-\sigma}$, and $\tilde{v}_{\tau,t} = \frac{\psi_\tau h_{\tau,t}^{1+v}}{1+v}$. A second-order approximation with respect to $\tilde{u}_{\tau,t}$ yields

$$\tilde{u}_{\tau,t} = \tilde{u}_\tau + \lambda_\tau c_\tau \left(\hat{c}_{\tau,t} + \frac{1-\sigma}{2} \hat{c}_{\tau,t}^2 \right) + \vartheta(\|\Xi\|^3).$$

Since at the efficient steady state $\lambda_\tau = \lambda$, we have

$$\begin{aligned} U_t^{(1)} &= \lambda \left[\theta \pi_s c_s \left(\hat{c}_{s,t} + \frac{1-\sigma}{2} \hat{c}_{s,t}^2 \right) + \theta \pi_b c_b \left(\hat{c}_{b,t} + \frac{1-\sigma}{2} \hat{c}_{b,t}^2 \right) \right. \\ &\quad \left. + (1-\theta) \pi_s c_s \left(\hat{c}_{s,t}^* + \frac{1-\sigma}{2} (\hat{c}_{s,t}^*)^2 \right) + (1-\theta) \pi_b c_b \left(\hat{c}_{b,t}^* + \frac{1-\sigma}{2} (\hat{c}_{b,t}^*)^2 \right) \right] \\ &\quad + t.i.p. + \vartheta(\|\Xi\|^3) \\ &= \lambda \left\{ \bar{y}_t + \frac{1}{2} (1-\sigma) \bar{y}_t^2 + \sigma \bar{y}_t \bar{g}_t - \frac{\sigma}{2} \left[\theta (1-\theta) (\hat{c}_t^D)^2 \right. \right. \\ &\quad \left. \left. + \frac{\pi_s c_s \pi_b c_b}{\sigma^2} [(\bar{\lambda}_{R,t})^2 + \theta (1-\theta) (\hat{\lambda}_{R,t}^D)^2] \right] \right\} + t.i.p. + \vartheta(\|\Xi\|^3) \\ &= \lambda \left\{ \bar{y}_t + \frac{1}{2} (1-\sigma) \bar{y}_t^2 + \sigma \bar{y}_t \bar{g}_t - \frac{1}{2\sigma} \left[\theta (1-\theta) \pi_b c_b (\hat{\lambda}_{R,t}^D)^2 + \pi_s c_s \pi_b c_b (\bar{\lambda}_{R,t})^2 \right] \right\} \\ &\quad + t.i.p. + \vartheta(\|\Xi\|^3), \end{aligned}$$

where $\hat{c}_t^D = (\pi_s c_s \hat{c}_{s,t} + \pi_b c_b \hat{c}_{b,t}) - (\pi_s c_s \hat{c}_{s,t}^* + \pi_b c_b \hat{c}_{b,t}^*)$. The following equations are used in the above derivation:

$$\begin{aligned} \bar{y}_t + \frac{1}{2} \bar{y}_t^2 - \bar{g}_t &= \left[\theta \pi_s c_s \left(\hat{c}_{s,t} + \frac{1}{2} (\hat{c}_{s,t})^2 \right) + \theta \pi_b c_b \left(\hat{c}_{b,t} + \frac{1}{2} (\hat{c}_{b,t})^2 \right) \right. \\ &\quad \left. + (1-\theta) \pi_s c_s \left(\hat{c}_{s,t}^* + \frac{1}{2} (\hat{c}_{s,t}^*)^2 \right) + (1-\theta) \pi_b c_b \left(\hat{c}_{b,t}^* + \frac{1}{2} (\hat{c}_{b,t}^*)^2 \right) \right] \\ &\quad + t.i.p. + \vartheta(\|\Xi\|^3), \\ \hat{\lambda}_{\tau,t} &= -\sigma \hat{c}_{\tau,t}, \\ \hat{\lambda}_{s,t} &= \hat{\lambda}_{s,t}^* + \vartheta(\|\Xi\|^2), \end{aligned}$$

$$\hat{c}_t^D = \frac{\pi_b c_b}{\sigma} \hat{\lambda}_{R,t}^D + \vartheta(\|\Xi\|^2).$$

4.A. Appendix

On the labor side, households' first-order conditions imply

$$\frac{\psi_s h_{s,t}^v}{\lambda_{s,t}} = \frac{\psi_b h_{b,t}^v}{\lambda_{b,t}} = w_t.$$

Together with $h_t = \pi_s h_{s,t} + \pi_b h_{b,t}$, we have

$$\frac{h_{s,t}}{h_s} = \frac{\frac{h_t}{h} \left(\frac{\lambda_{s,t}}{\lambda}\right)^{1/v}}{\tilde{\lambda}_t}, \quad \frac{h_{b,t}}{h_b} = \frac{\frac{h_t}{h} \left(\frac{\lambda_{b,t}}{\lambda}\right)^{1/v}}{\tilde{\lambda}_t},$$

with $\tilde{\lambda}_t = \pi_s \frac{h_s}{h} \left(\frac{\lambda_{s,t}}{\lambda}\right)^{1/v} + \pi_b \frac{h_b}{h} \left(\frac{\lambda_{b,t}}{\lambda}\right)^{1/v}$. The average disutility of labor in Home can be written as

$$\pi_s \tilde{v}_{s,t} + \pi_b \tilde{v}_{b,t} = \frac{1}{1+v} \left(\frac{h_t}{\tilde{\lambda}_t}\right)^{1+v} \tilde{\Lambda}_t,$$

with $\tilde{\Lambda}_t = \pi_s \psi_s \left(\frac{h_s}{h}\right)^{1+v} \left(\frac{\lambda_{s,t}}{\lambda}\right)^{1+1/v} + \pi_b \psi_b \left(\frac{h_b}{h}\right)^{1+v} \left(\frac{\lambda_{b,t}}{\lambda}\right)^{1+1/v}$. A second-order Taylor expansion of this equation yields

$$\pi_s \tilde{v}_{s,t} + \pi_b \tilde{v}_{b,t} = \lambda \left[\frac{h_t - h}{h} + \frac{v}{2} \left(\frac{h_t - h}{h}\right)^2 + \frac{\pi_s \tilde{h}_s \pi_b \tilde{h}_b}{2v} \hat{\lambda}_{R,t}^2 \right] + t.i.p. + \vartheta(\|\Xi\|^3),$$

with $\tilde{h}_\tau = h_\tau/h$. To derive an expression for $(h_t - h)/h$ in terms of output, I make use of the production functions and the labor market clearing conditions. For Home, we have

$$\frac{h_t - h}{h} = \frac{1}{\theta h} \int_0^\theta h_t(j) dj - 1 = \frac{1}{\theta h z_t} \int_0^\theta y_t(j) dj - 1.$$

A second-order Taylor expansion of the above equation yields

$$\begin{aligned} \frac{1}{\theta h z_t} \int_0^\theta y_t(j) dj &= \mathbb{E}_j[\hat{y}_t] + \frac{1}{2} \text{Var}_j[\hat{y}_t] + \frac{1}{2} (\mathbb{E}_j[\hat{y}_t])^2 \\ &\quad - \hat{z}_t - \hat{z}_t \mathbb{E}_j[\hat{y}_t] + t.i.p. + \vartheta(\|\Xi\|^3), \end{aligned}$$

with $\mathbb{E}_j[\hat{y}_t] = \frac{1}{\theta} \int_0^\theta \hat{y}_t(j) dj$ and $\text{Var}_j[\hat{y}_t] = \frac{1}{\theta} \int_0^\theta (\hat{y}_t(j) - \mathbb{E}_j[\hat{y}_t])^2 dj$. Furthermore, from $y_t = \left[\left(\frac{1}{\theta}\right) \int_0^\theta y_t(j) \frac{\mu-1}{\mu} dj \right]^{\frac{\mu}{\mu-1}}$ we have

$$\mathbb{E}_j[\hat{y}_t] = \hat{y}_t + \vartheta(\|\Xi\|^2),$$

4.A. Appendix

$$\mathbb{E}_j[\hat{y}_t] = \hat{y}_t - \frac{1}{2} \frac{\mu - 1}{\mu} \text{Var}_j[\hat{y}_t] + \vartheta(\|\Xi\|^3).$$

Using the the above equation to eliminate $\mathbb{E}_j[\hat{y}_t]$, we arrive at

$$\frac{h_t - h}{h} = \hat{y}_t + \frac{1}{2} \hat{y}_t^2 + \frac{1}{2\mu} \text{Var}_j[\hat{y}_t] - \hat{z}_t - \hat{z}_t \hat{y}_t + t.i.p. + \vartheta(\|\Xi\|^3).$$

With the corresponding equations for Foreign, on the union-level we have

$$\begin{aligned} U_t^{(2)} &= \lambda \left[\bar{y}_t + \frac{1}{2} (v+1) \bar{y}_t^2 + \frac{1}{2} (v+1) \theta (1-\theta) \hat{\tau}_t^2 \right. \\ &\quad \left. + \frac{1}{2\mu} \left(\theta \text{Var}_j[\hat{y}_{H,t}] + (1-\theta) \text{Var}_j[\hat{y}_{F,t}] \right) \right. \\ &\quad \left. - \theta (v+1) \hat{z}_t \hat{y}_t - (1-\theta) (v+1) \hat{z}_t^* \hat{y}_t^* \right. \\ &\quad \left. + \frac{\pi_s \tilde{h}_s \pi_b \tilde{h}_b}{2v} \left[(\bar{\lambda}_{R,t})^2 + \theta (1-\theta) (\hat{\lambda}_{R,t}^D)^2 \right] \right] + t.i.p. + \vartheta(\|\Xi\|^3) \end{aligned}$$

$\text{Var}_j[\hat{y}_{H,t}]$ is then substituted for with the following expression

$$\begin{aligned} \text{Var}_j[\hat{y}_{H,t}] &= \mu^2 \text{Var}_j[\hat{p}_{H,t}] \\ &= \mu^2 \left[\alpha^{t+1} \text{Var}_j[\hat{p}_{H,-1}] + \frac{\alpha}{1-\alpha} \sum_{k=0}^t \alpha^{t-k} (\hat{\Pi}_{H,k})^2 \right]. \end{aligned}$$

Finally, we can rewrite the central bank's objective function as to minimize

$$\begin{aligned} & - \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t + t.i.p. + \vartheta(\|\Xi\|^3), \\ \mathcal{L}_t &= (\bar{y}_t)^2 + \frac{1}{v+\sigma} \left[(v+1) \theta (1-\theta) \hat{\tau}_t^2 + \frac{\mu}{\kappa} [\theta (\hat{\Pi}_{H,t})^2 + (1-\theta) (\hat{\Pi}_{F,t})^2] \right. \\ &\quad \left. - 2\theta (v+1) \hat{z}_t \hat{y}_t - 2(1-\theta) (v+1) \hat{z}_t^* \hat{y}_t^* - 2\sigma \bar{y}_t \bar{g}_t \right] \\ &\quad + \Omega (\bar{\lambda}_{R,t})^2 + \theta (1-\theta) \Omega^D (\hat{\lambda}_{R,t}^D)^2 \\ &= \theta (x_t)^2 + (1-\theta) (x_t^*)^2 + \frac{\mu}{\kappa} \hat{\Pi}_t^2 + \left[\frac{1-\sigma}{v+\sigma} + \frac{\mu}{\kappa} \right] \theta (1-\theta) \hat{\tau}^2 \\ &\quad + \Omega (\bar{\lambda}_{R,t})^2 + \Omega^D (\hat{\lambda}_{R,t}^D)^2 \end{aligned}$$

4.A. Appendix

with $\Omega = \frac{1}{v+\sigma} \left(\frac{\pi_s \bar{h}_s \pi_b \bar{h}_b}{v} + \frac{\pi_s c_s \pi_b c_b}{\sigma} \right)$, $\Omega^D = \frac{\theta(1-\theta)}{v+\sigma} \left(\frac{\pi_s \bar{h}_s \pi_b \bar{h}_b}{v} + \frac{\pi_b c_b}{\sigma} \right)$. x_t is the output gap defined as deviation from the efficient output.

4.A.6 Optimal target criterion in the simplified model

In this section, I characterize optimal monetary policy for the simplified model. Using the definition of output gap x_t and the assumptions outlined in the main text, the Phillips curve can be rewritten as

$$\hat{\Pi}_t = \beta \mathbb{E}_t \hat{\Pi}_{t+1} + \kappa \bar{x}_t. \quad (4.A.38)$$

As discussed in main text, it is furthermore assumed that

$$\begin{aligned} \hat{\omega}_t &= -\tilde{\Phi}_\pi \hat{\Pi}_t - \tilde{\Phi}_y (\phi_{T,y} \hat{y}_t - \tilde{g}_t) + s_t \\ \hat{\omega}_t^* &= -\tilde{\Phi}_\pi^* \hat{\Pi}_t - \tilde{\Phi}_y^* (\phi_{T,y}^* \hat{y}_t^* - \tilde{g}_t^*) + s_t^* \\ \bar{\lambda}_{R,t} &= -\tilde{\Phi}_\lambda \bar{\omega}_t \\ \hat{\lambda}_{R,t}^D &= -\tilde{\Phi}_\lambda^D \hat{\omega}_t^D. \end{aligned}$$

Under these assumptions, the average and regional difference of relative marginal utility can be expressed as:

$$\begin{aligned} \bar{\lambda}_{R,t} &= \tilde{\Phi}_\lambda \bar{\Phi}_\pi \hat{\Pi}_t + \tilde{\Phi}_\lambda \bar{\Phi}_y \bar{y}_t \\ &\quad - \tilde{\Phi}_\lambda \left[\theta \tilde{\Phi}_y \tilde{g}_t + (1-\theta) \tilde{\Phi}_y^* \tilde{g}_t^* + \bar{s}_t \right], \end{aligned} \quad (4.A.39)$$

$$\begin{aligned} \hat{\lambda}_{R,t}^D &= \tilde{\Phi}_\lambda^D \tilde{\Phi}_\pi^D \hat{\Pi}_t + \tilde{\Phi}_\lambda^D \tilde{\Phi}_y^D \hat{y}_t \\ &\quad - \tilde{\Phi}_\lambda^D \left[\tilde{\Phi}_y \tilde{g}_t - \tilde{\Phi}_y^* \tilde{g}_t^* + s_t^D \right], \end{aligned} \quad (4.A.40)$$

with

$$\begin{aligned} \bar{\Phi}_\pi &= \theta \tilde{\Phi}_\pi + (1-\theta) \tilde{\Phi}_\pi^*, \\ \bar{\Phi}_y &= \theta \tilde{\Phi}_y \Phi_{T,y} + (1-\theta) \tilde{\Phi}_y^* \Phi_{T,y}^*, \\ \tilde{\Phi}_y^D &= \tilde{\Phi}_y \Phi_{T,y} - \tilde{\Phi}_y^* \Phi_{T,y}^*, \\ \tilde{\Phi}_\pi^D &= \tilde{\Phi}_\pi - \tilde{\Phi}_\pi^*, \end{aligned}$$

4.A. Appendix

$$\tilde{\Phi}_y^D = \tilde{\Phi}_y \Phi_{T,y} - \tilde{\Phi}_y^* \Phi_{T,y}^*.$$

The second-order approximation to the welfare-theoretical loss function (4.12) becomes

$$L_t = \bar{x}_t^2 + \frac{\mu}{\kappa} \hat{\Pi}_t + \Omega (\bar{\lambda}_{R,t})^2 + \Omega^D (\hat{\lambda}_{R,t}^D)^2.$$

Optimal monetary policy is derived by minimizing the expected future discounted value of L_t subject to the constraints (4.A.38)-(4.A.41). The optimization results in the following target criterion:

$$\begin{aligned} \mu \hat{\Pi}_t + \Delta \bar{y}_t + \tilde{\Phi}_y \Omega \Delta \bar{\lambda}_{R,t} + \tilde{\Phi}_y^D \Omega^D \Delta \hat{\lambda}_{R,t}^D \\ \kappa \tilde{\Phi}_\pi \Omega \hat{\lambda}_{R,t} + \kappa \tilde{\Phi}_\pi^D \Omega^D \hat{\lambda}_{R,t}^D = 0. \end{aligned}$$

The target criterion can also be rewritten in terms of spreads:

$$\begin{aligned} \mu \hat{\Pi}_t + \Delta \bar{x}_t \\ - \Omega \tilde{\Phi}_\lambda \left[\left(\tilde{\Phi}_y + \kappa \tilde{\Phi}_\pi \right) \bar{\omega}_t - \tilde{\Phi}_y \bar{\omega}_{t-1} \right] \\ - \Omega^D \tilde{\Phi}_\lambda^D \left[\left(\tilde{\Phi}_y^D + \kappa \tilde{\Phi}_\pi^D \right) \hat{\omega}_t^D - \tilde{\Phi}_y^D \hat{\omega}_{t-1}^D \right] = 0 \end{aligned}$$

4.A.7 Coefficients for the adjusted target criterion

This section describes the calibration for the target criterion (4.13) in the main text. The coefficients are combinations of parameters in the simplified model, whose reduced forms aim to reflect the microfounded full model.

As shown in Appendix 4.A.6, weights in the welfare-loss function Ω and Ω^D are functions of structural parameters. Under the euro area calibration (see main text), we have

$$\Omega = 0.205, \text{ and } \Omega^D = 0.072.$$

Concerning the parameters $\tilde{\Phi}_y$ and $\tilde{\Phi}_y^*$, the simplifying assumption used in this paper follows the approach used in Corsetti et al. (2013) in linking the interest rate spread directly with government deficit. The expression $\xi/(\pi_b + s_\Omega)$ in their paper corresponds to $\tilde{\Phi}_y$ and $\tilde{\Phi}_y^*$ in this paper.

As the authors have pointed out, when choosing the parameters, one has to take into account the horizon over which deficits accumulate. In their setup, this means that the calibration has to reflect the period while the economy is at the zero lower bound. In the

4.A. Appendix

current setup, deviation from steady state is driven by shocks. Given the persistence of the disturbances, absent further shocks, it will on average take 16 quarters for the model variables to return to their steady state after an initial hit. Using the same formula as suggested in Corsetti et al. (2013), and with steady state debt-to-GDP ratios of 90% in Home and 130% in Foreign, we have

$$\tilde{\Phi}_y = 0.042, \text{ and } \tilde{\Phi}_y^* = 0.130.$$

Turning to $\tilde{\Phi}_\pi$ and $\tilde{\Phi}_\pi^*$, from equation (4.8) we see that the impact of inflation on the current government debt - and thus on private sector spreads - are proportional to that of deficit: $\tilde{\Phi}_\pi/\tilde{\Phi}_y = \chi_g b^g q^g$ and $\tilde{\Phi}_\pi^*/\tilde{\Phi}_y^* = \chi_g^* b^{g^*} q^{g^*}$. As a result, we have

$$\tilde{\Phi}_\pi = 0.102, \text{ and } \tilde{\Phi}_\pi^* = 0.351.$$

Finally, solving equation (4.2) forward we have

$$\begin{aligned} \bar{\lambda}_{R,t} &= - \sum_{j=0}^{\infty} \delta^j \bar{\omega}_{t+j} \\ &= -\alpha^\psi \sum_{j=0}^{\infty} \delta^j \bar{\omega}_{t+j}^g \end{aligned}$$

The evolution of the government spreads generally depends on the specific disturbances and the model calibration. To the extent that the dynamic can be reasonably approximated by an AR(1) process - as the exogenous disturbances, the above equation can be rewritten as

$$\bar{\lambda}_{R,t} = -\frac{\alpha^\psi}{1 - \delta\rho^\omega} \bar{\omega}_t^g,$$

with $\rho^\omega \in (0, 1)$ reflecting the persistence of the government spreads. Using equation (4.5) and following the same argument, we have

$$\bar{\lambda}_{R,t}^D = -\frac{\alpha^\psi}{1 - \delta\rho^\omega} \bar{\omega}_t^{g,D}.$$

Assuming $\rho^\omega = 0.95$, the calculation yields

$$\tilde{\Phi}_\lambda = \tilde{\Phi}_\lambda^D = 5.641$$

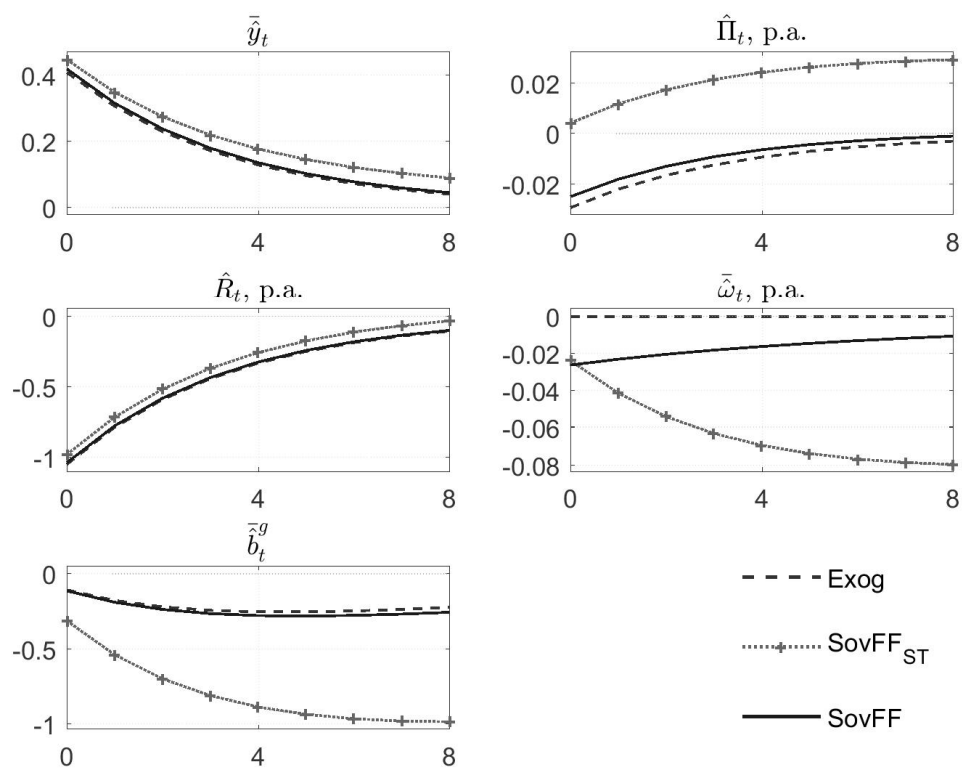
4.A. Appendix

Taken all together, we have the following parametrization for the target criterion:

$$7.667 \hat{\Pi}_t + \Delta \bar{x}_t - 0.045 \bar{\omega}_t + 0.041 \bar{\omega}_{t-1} + 0.019 \hat{\omega}_t^D - 0.018 \hat{\omega}_{t-1}^D = 0.$$

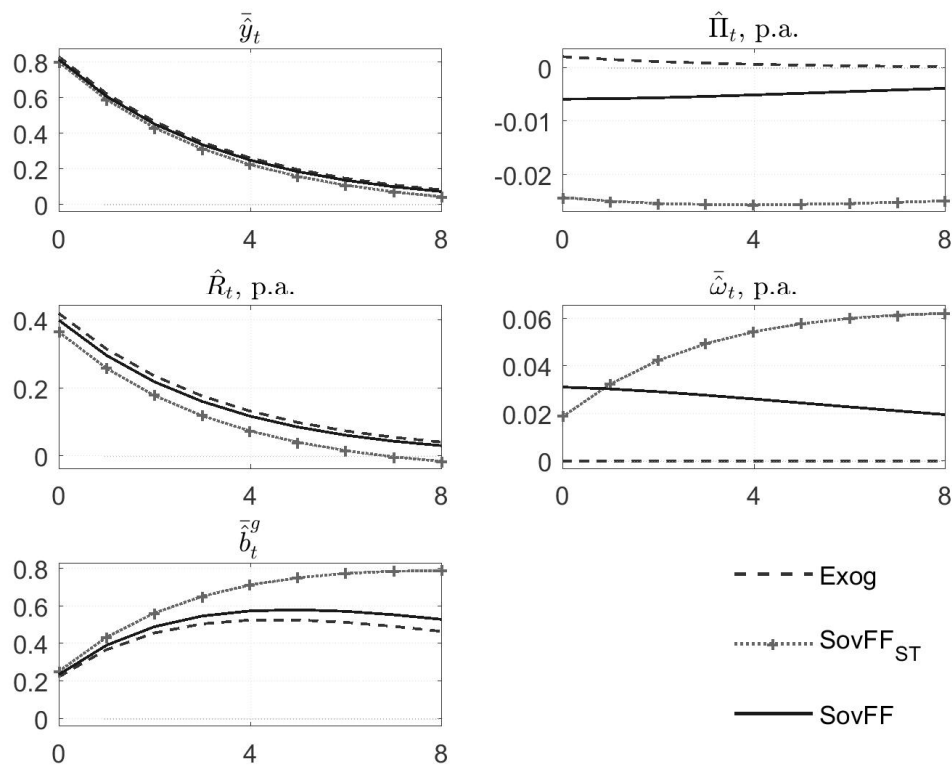
4.A.8 Impulse responses under the Taylor rule

Figure 4.8: Impulse responses under the Taylor rule



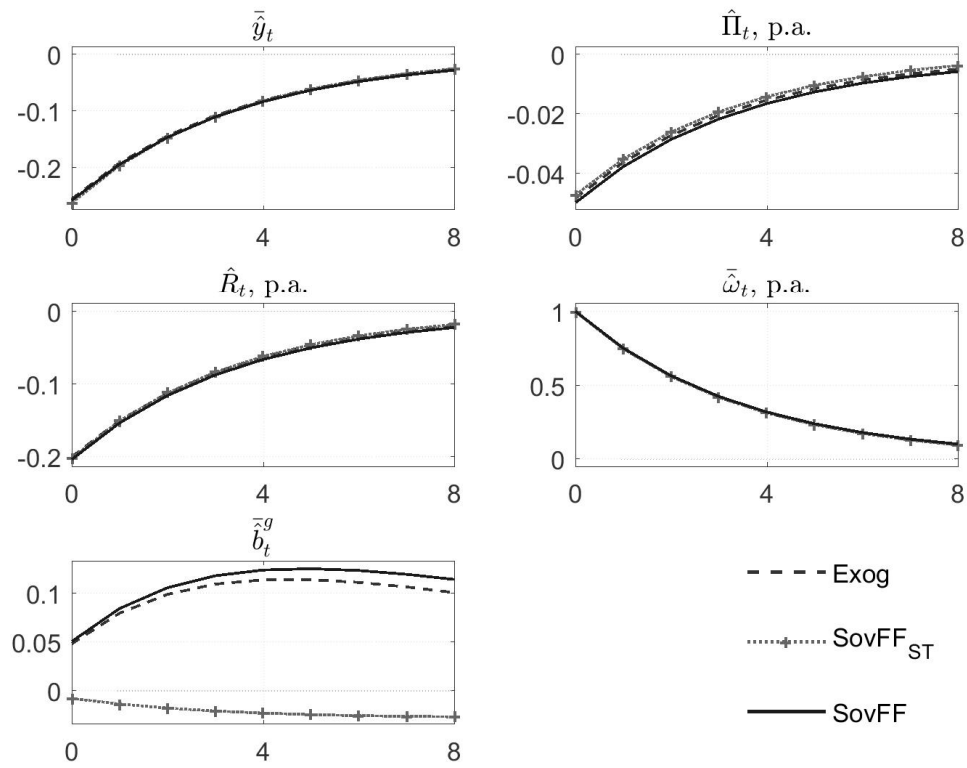
(a) Impulse response under the Taylor rule and with long-term government bonds, to a technology shock of 1% (z and z^*)

4.A. Appendix



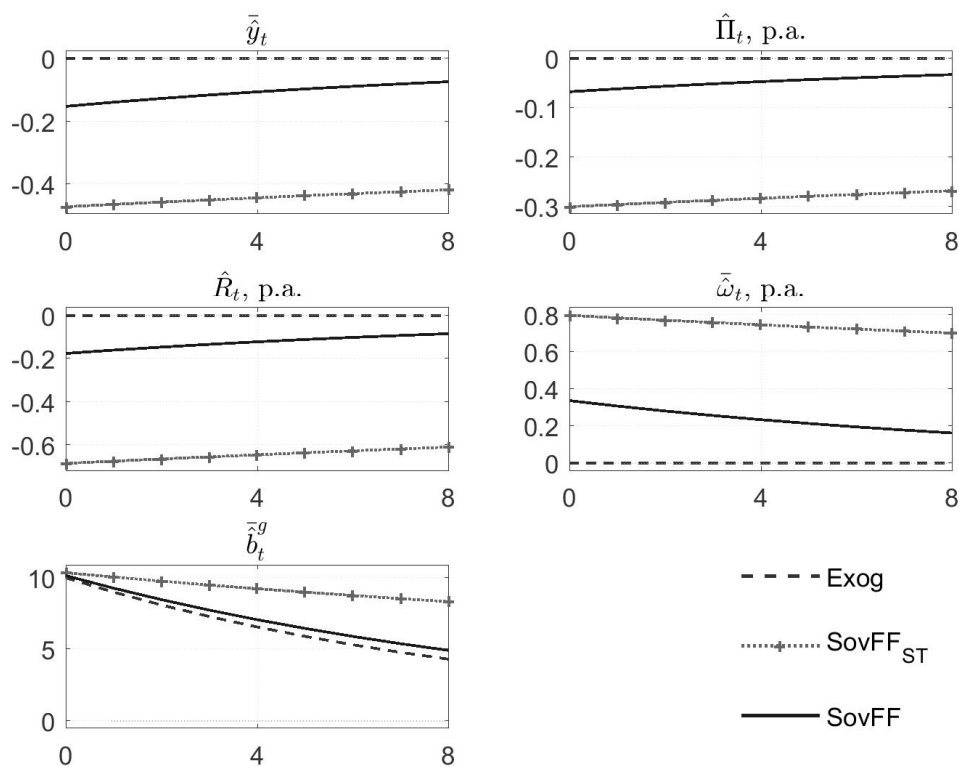
(b) Impulse response under the Taylor rule and with long-term government bonds, to a government spending shock of 1% of steady state output (\tilde{g} and \tilde{g}^*)

4.A. Appendix



(c) Impulse response under the Taylor rule and with long-term government bonds, to private sector financial shocks that increase private sector spreads initially by 1 percentage point (annualized) (s and s^*)

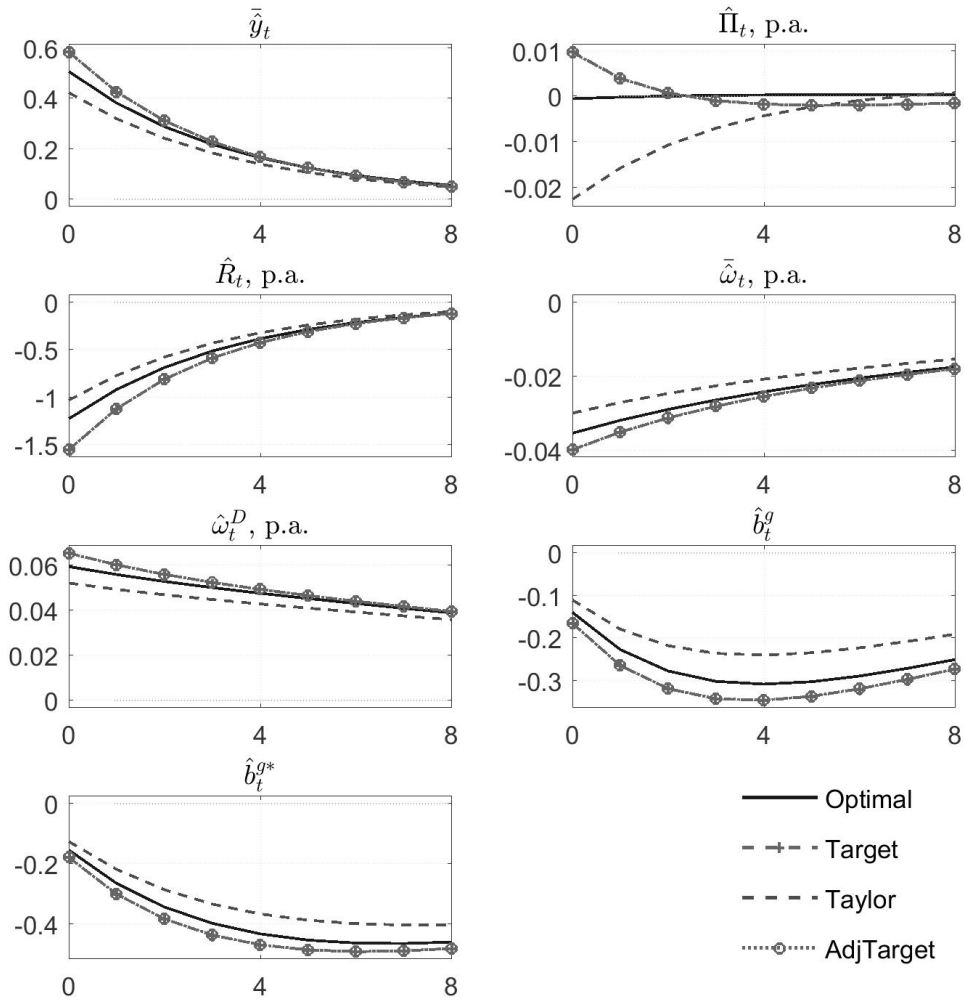
4.A. Appendix



(d) Impulse response under the Taylor rule and with long-term government bonds, to a 10 percentage points increase in government debt (ϵ^g and ϵ^{g*})

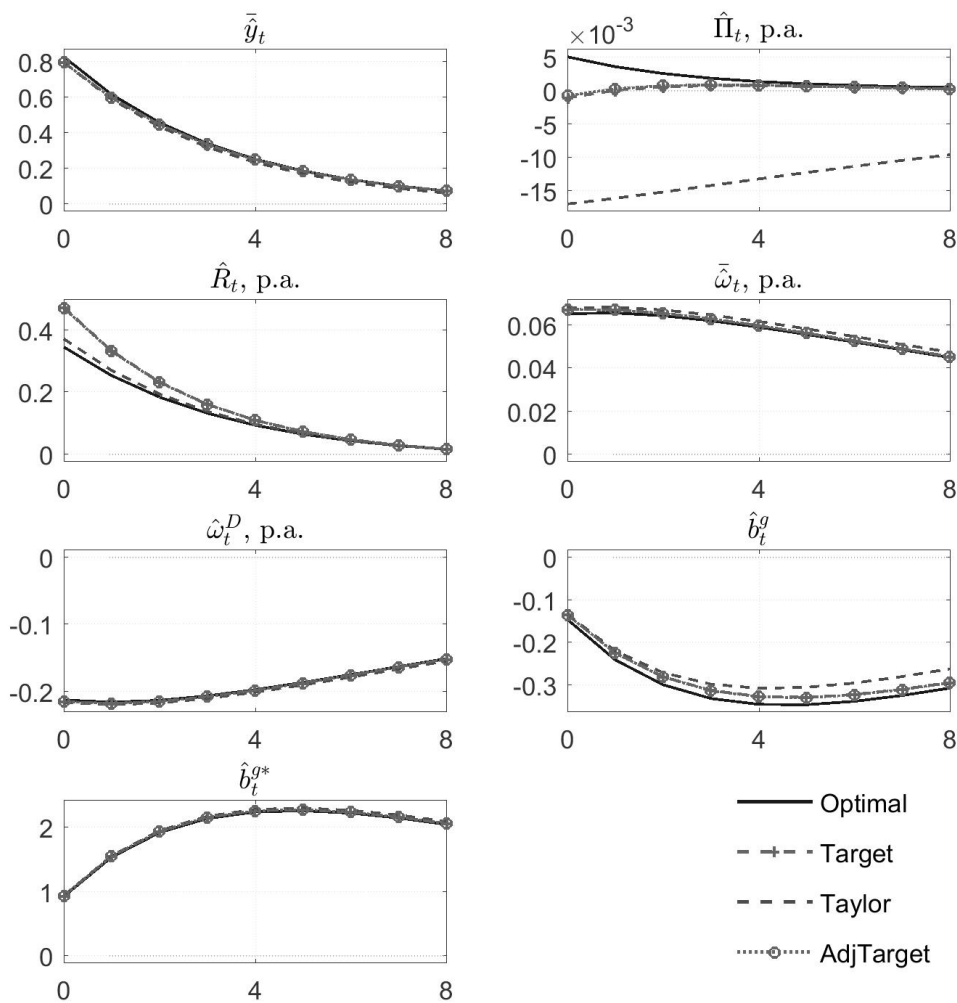
4.A.9 Impulse responses under alternative monetary policies

Figure 4.9: Impulse responses under alternative monetary policies



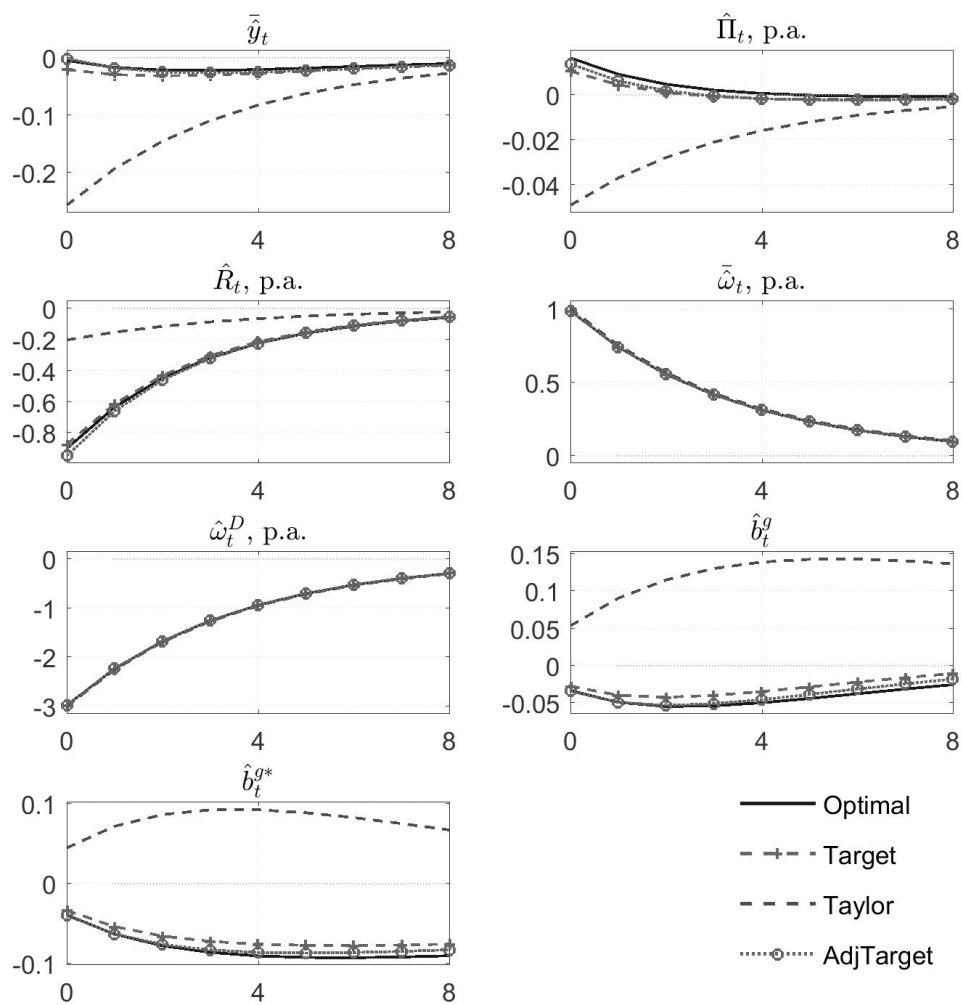
(a) Impulse responses (%) to Foreign technology level (z^*), under alternative monetary policies and with long-term government bonds.

4.A. Appendix



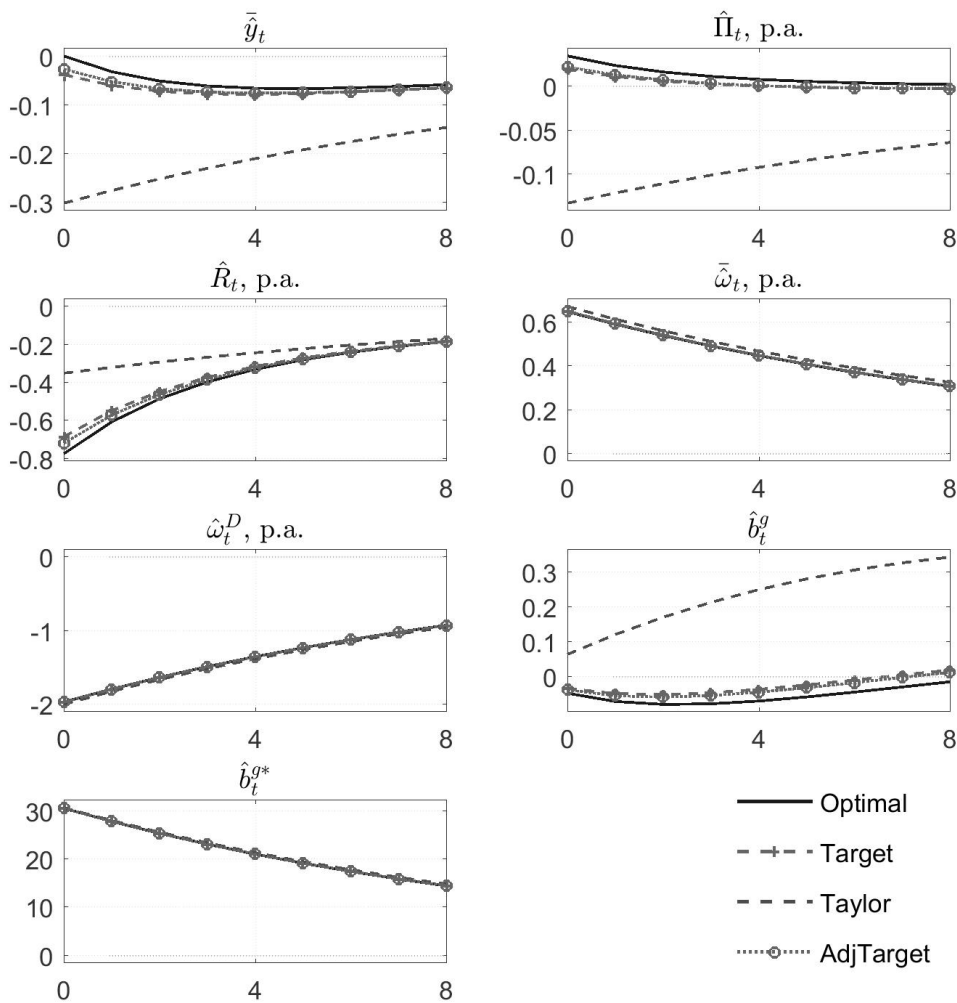
(b) Impulse responses (%) to Foreign government spending (g^*), under alternative monetary policies and with long-term government bonds.

4.A. Appendix



(c) Impulse responses (%) to Foreign private sector spread shock (s^*), under alternative monetary policies and with long-term government bonds.

4.A. Appendix



(d) Impulse responses (%) to Foreign government debt shock (ϵ^{g*}), under alternative monetary policies and with long-term government bonds.

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