Essays on Monetary Policy Interactions with Fiscal Policy and Financial Markets

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to my parents

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Introduction

Modern macroeconomic theory has largely developed into a positive discipline seeking to set up models which improve our understanding of economic mechanisms and interrelations among key economic variables. This development has been paralleled by a natural complementary step, namely the use of macroeconomic models to make positive, but also normative judgements about government policies. Along both of these dimensions, the analysis of monetary policy stands out prominently. The reason for this interest among academics, policy makers and the general public alike is the by now robust empirical evidence *"that monetary policy significantly affects the short-term course of the real economy ... [and] that the choice of how to conduct monetary policy has important consequences for aggregate activity"* [Clarida, Galí and Gertler (1999, p. 1661)] both over the business cycle and with respect to an economy's long-run growth performance.

This dissertation aims at contributing to the literature investigating the positive and normative framework for monetary policy. It provides an assessment of macroeconomic (i.e. monetary and to some extent also fiscal) policies by focusing on two rather distinct dynamic general equilibrium environments which help shed light on a number of critical aspects regarding the dynamic conduct of monetary policy. The main questions asked are of both theoretical and empirical nature and concern the way monetary policy interacts with fiscal policy and financial markets: How does nominal government debt shape the incentives faced by monetary policy makers? What is the nature of the monetary time consistency problem when there is interaction with sequential fiscal policy makers? Can the dynamic interplay of monetary and fiscal policies explain the evolution of government debt and inflation? How can we rationalize the negative correlation between inflation and aggregate productivity observed at business cycle frequency? What role do nominal interest rates and the provision of liquidity play in this context?

A unifying starting point for the set of models laid out in this thesis are specifications proposing that monetary policy does not operate in isolation, but interacts with other agents or institutions. The first two chapters concentrate on the strategic aspects underlying the interaction of monetary and fiscal policies in an economy characterized by positive amounts of government debt in nominal denomination. Specifically, in order to reexamine the time consistency properties of optimal monetary policy, chapter one poses a dynamic optimal taxation problem where not only monetary, but also fiscal policies are sequentially implemented. Starting from this scenario, the next chapter provides a positive theory of dynamic monetary-fiscal interactions and a reflection on the institution of monetary conservatism, whose role is shown to be inherently determined via its implications for the interaction with fiscal policy. The third chapter takes a different and more empirically oriented route: It elaborates on an incomplete markets environment in order to demonstrate how monetary policy systematically affects an economy's aggregate productivity. Key for this conclusion is to acknowledge that nominal fluctuations induced by monetary policy on the one hand and financial markets' capacity to intermediate scarce liquidity on the other hand interact in a way that has an important influence on corporate activity, thus affecting aggregate productivity.

In trying to answer the questions raised above, this dissertation concentrates on a few selected issues within the vast field of monetary economics. The selection of problems as well as the modelling framework represent a view of monetary policy which stresses its systematic role and largely abstracts from stabilization considerations. In a way, this emphasis is motivated by the observation that *"the potential for welfare gains from better long-run, supply-side policies exceeds* by far *the potential from further improvements in short-run demand management"* [Lucas (2003, p.1)]. As hinted above, we devote particular attention to the interaction of monetary policy with fiscal policy on the one hand and financial markets on the other hand. The emphasis on these interactions, in turn, brings game-theoretic and contract-theoretic problems to the forefront. By embedding these aspects into a dynamic general equilibrium environment, this thesis attempts to enhance our understanding of how and where government policies can impinge on the economy. The relevant arguments to be developed in the following hinge on policies' impact on interest rates and inflation as well as on the associated frictions: In the public finance model underlying the first two chapters, the equilibrium nominal interest rate is the relative price at which private agents are willing to hold government debt, but it also affects their trade-off between consumption and leisure. The financial markets friction stressed in the third chapter gives rise to a well-defined concept of corporate liquidity demand, whereby it is shown that the premium at which liquid assets trade is a function of the rate of inflation.

The following section provides a short discussion of a number of conceptual and methodological questions. Moreover, it reviews some of the general literature[1] and,

[1]For excellent reviews on monetary theory and policy, see e.g. the textbook treatments in Walsh (2003) and Woodford (2003), the review article on monetary policy by Clarida, Galí and Gertler (1999), the study by McCandless and Weber (1995) or the lecture on the welfare costs of inflation by Lucas (2000).

in passing by, highlights the links to the respective chapters in this dissertation. The review is organized according to five broad themes, starting with models of money and the transmission of monetary policy, then addressing concepts of optimal (monetary) policy and the role of government debt in the dynamics of monetary-fiscal interactions, before concluding with a remark on the merits of general equilibrium approaches to the problems at hand. Necessarily, this synopsis will remain rather coarse; throughout, we abstain from synthesizing the relevant empirical evidence in order to concentrate on theoretical issues. A more detailed review of the literature which is of specific interest to the problems raised in this dissertation is deferred to the individual chapters.

Literature, framework and methodology

Models of money and monetary policy: Evidently, any theoretical analysis of monetary policy is conditional on a specific conceptual foundation. In the context of the present dissertation, a number of modelling approaches to monetary theory deserve particular attention. A common characteristic they share is their focus on monetary policy's systematic public finance role (chapters one and two) and on its supply-side effects (chapter three) rather than on the effects on aggregate demand familiar from New Keynesian setups.[2]

To begin with, there are modifications of the basic neoclassical growth model set up to embrace monetary phenomena by deriving a demand for real balances from a transactions motive; often, this is achieved via a cash-in-advance restriction.[3] These models are generally built on the presumption of flexible prices and are thus particularly suited for investigating long-run interrelations and structural problems, while they have only limited success in replicating the stylized empirical facts regarding the short-run comovement of monetary and real variables over the business cycle.

[2]Faced with both the advances and the shortcomings of the real business cycle literature, models summarized under the heading "New Keynesian" came into existence in an effort to match the empirical short-run dynamics in response to exogenous shocks and especially to policy innovations. This family of models is based on the notion of nominal rigidities in the formation of prices and/or wages and is generally cast in a framework of monopolistic competition; compare e.g. Blanchard and Kiyotaki (1987). New Keynesian models feature versions of the Phillips curve as their key building block and turned out well-suited for the analysis of monetary policy which works via its effect on aggregate demand and is generally seen as commissioned with the task of stabilizing economic fluctuations. For a recent example of monetary policy analysis based on a (significantly extended) version of a prototype New Keynesian model, compare Christiano, Eichenbaum and Evans (2005). Since the individual chapters of this dissertation do not rest on such a New Keynesian framework, at this stage, we refrain from reviewing it more extensively; the same applies for the recent advances adopting a sticky information perspective, see e.g. Mankiw and Reis (2002).

[3]An alternative and for the most part equivalent specification stipulates real balances as directly yielding utility.

Nevertheless, this branch of models constitutes an analytically convenient and insightful laboratory for studying, among other things, (i) the fundamental quantity relation between money, output and prices, (ii) the expectations-driven interrelation between inflation and nominal interest rates underlying the Fisher equation, (iii) fundamental issues in asset pricing, (iv) the role of inflation as a tax and its induced welfare costs, as well as (v) the public finance considerations of monetary policy arising via the consolidated intertemporal government budget constraint. The first two chapters in this dissertation employ a formal structure which pertains to this class of models. The rationale for this choice is that the chapters elaborate on a monetary time consistency problem stemming from the lump-sum aspect of the inflation tax in an economy with positive amounts of nominal government debt. A basic perfectly competitive economy without any nominal rigidities is sufficient to analyze the key mechanisms involved and has the additional advantage of resting on a conceptually more stringent foundation.[4]

Relatedly, following a seminal contribution by Lucas (1990) another category of monetary business cycle models maintains the assumption of flexible prices, but, in addition to the cash constraint on transactions, imposes short-run restrictions on certain financial transactions for a subset of economic agents. In these limited asset market participation models, the non-neutrality of monetary policy arises as a consequence of the implicit nominal rigidity in agents' asset portfolios which cannot be promptly reorganized as new information hits the economy. A central empirical prediction derived from this setup is the liquidity effect, i.e. a negative correlation of unanticipated money expansions and nominal interest rates in the short-run. The third chapter of this dissertation employs a model of the limited participation variety because this framework allows to conveniently incorporate supply-side effects of monetary policy under the additional assumption that firms need to finance part of their factor remuneration in advance.[5] Moreover, with limited asset market participation, it is straightforward to include institutions of financial intermediation into the model in a meaningful way. In view of the chapter's objective to establish a link from monetary fluctuations to the endogenous selection of available production technologies which is transmitted via monetary policy's implications for the comprehensiveness of financial intermediation, this is an important consideration.[6]

[4]The point is that the literature starting from nominal rigidities and imperfect competition generally assumes, either explicitly or implicitly, that the government has access to lump-sum taxes to finance its budget as well as to production subsidies for the purpose of eliminating monopoly distortions in product and factor markets; these assumptions are not well-aligned with the public finance problem addressed in this thesis. See, however, Schmitt-Grohé and Uribe (2004) for a unifying approach which reconciles the two frameworks.

[5]This assumption gives rise to a cost channel of monetary transmission; compare e.g. Barth and Ramey (2001).

[6]Finally, to give a balanced account of the literature, the recent strand of research addressing

Monetary transmission: The key aspect of the monetary transmission mechanism which is formalized in the basic models of the neoclassical growth and limited participation varieties is an interest rate channel. Interest rates influence economic activity by affecting various relative prices in the economy. In a closed economy, these are primarily the relative prices of capital and of future consumption in terms of current consumption; moreover, nominal interest rates act as an additional opportunity cost of consumption on the consumption-leisure margin because the cash constraint on transactions implies that agents need to forego interest rate earnings on assets which, unlike cash balances, have a positive rate of return. Government bonds constitute an important class of such alternative assets. In the spirit of Lucas and Stokey (1983), chapters one and two employ a deterministic monetary model without capital, but with nominal government debt; this framework is useful for illustrating the role of expectations for the determination of nominal interest rates. At the same time, the conduct of monetary policy is crucial for shaping the public's expectations. Under the maintained benchmark hypothesis of a sequentially optimal implementation of monetary policy, there results an interesting fixed point property in that an equilibrium requires (i) that monetary policy is optimal, given predetermined private expectations, and (ii) that the formation of expectations must rationally anticipate the ex post incentives faced by monetary policy. However, it will be illustrated that the determination of such equilibrium does critically hinge on the specification of fiscal policy. This underpins that monetary-fiscal interactions are an important factor in the transmission of monetary policies.[7]

The interest rate channel encompasses a set of mechanisms which basically unfold even in a Modigliani-Miller environment, i.e. independent of the existence of any financial market frictions. However, financial frictions can play a crucial role in amplifying the transmission mechanism and may even be a source of fluctuations on their own.[8] Against this background, the bank lending channel

questions in monetary theory and policy from a search-theoretic perspective should also be mentioned; see e.g. Kiyotaki and Wright (1993) for an early example. In contrast to the previously discussed approaches, which start from an exogenously stipulated role for money, this literature is explicit about the deep determinants of money demand by endogenously deriving it from a search and matching framework. For some time, a drawback with this line of research has been that it rests on highly stylized models which, in order to maintain tractability, abstract from empirically important phenomena and thus preclude plausible business cycle analysis or policy recommendations. Although, as reported in Lagos and Wright (2005), there has been much progress along these latter dimensions, this dissertation throughout retains the standard assumption of Walrasian markets in order to focus on the particular problems it aims to analyze in greater detail.

[7] See chapter 23 in Ljungqvist and Sargent (2004) for a textbook illustration of how the inflationary consequences of a given monetary open market operation depend on the specification of fiscal policy.

[8] On these issues, compare e.g. Kocherlakota (2000) and Suarez and Sussman (1997).

and the credit channel, each resting on the interaction of monetary policy with particular financial market frictions, are important concepts.[9] The bank lending channel attributes the effects of monetary policy to movements in the supply of bank credit. The essential feature of this transmission mechanism is that monetary policy can affect the supply of credit by financial intermediaries by altering the quantity of base money, thus changing the cost of capital faced by bank-dependent borrowers. The credit channel, in stressing a role for credit in general and not just bank lending, adopts a broader perspective. In a nutshell, the credit channel draws the line not between bank and non-bank sources of funds, but between internal and external sources of financing available to firms.[10] The generic implication of financial frictions then is that there exists an external finance premium and that corporate activity is constrained below its first best level due to the restricted availability of external funds. Since there is a wedge between the cost of internal and external finance, firm level investment becomes sensitive to variables such as net worth or cash flow. Whereas the bulk of the literature focuses on the interaction of monetary policy, capital market imperfections and *overall* investment (either at the aggregate, industry or firm level),[11] the third chapter of this dissertation considers the effects of nominal fluctuations on the *composition* of overall investment (again, at the three relevant levels of aggregation). Specifically, it allows for endogenous technology choice by entrepreneurial firms and stipulates a moral hazard problem for a subset of the available technologies. This facilitates a distinction between general short-term credit and liquidity, whereby the latter is used to hedge technology-specific production risks. Based on a limited participation setup, the model establishes a link from monetary policy to nominal interest rates and the liquidity premium, thus endogenizing the composition of aggregate investment and making the case for a liquidity-based notion of monetary transmission.

Optimal policy and commitment versus discretion: The problem of optimal monetary and fiscal policy is the problem of assigning monetary and fiscal instruments in a way such as to maximize social welfare. As will be argued below, the respective problems facing monetary and fiscal policy makers cannot be treated

[9] For an overview, compare e.g. chapter 7 in Walsh (2003). The starting point for these transmission channels are agency problems arising from assymmetric information in financial markets; the latter can give rise to adverse selection, moral hazard or monitoring costs. Important theoretical foundations are due to, among others, Stiglitz and Weiss (1981), Hart and Moore (1994) and Townsend (1979).

[10] The credit view also stresses the importance of heterogeneity among corporate borrowers, e.g. between small and large firms; compare e.g. Bernanke, Gertler and Gilchrist (1996), Gertler and Gilchrist (1994) or, more recently, Cooley and Quadrini (2006) for a setup with explicit dynamics among heterogenous, financially constrained firms.

[11] For a review of the theoretical and empirical literature on the effect of financial frictions on corporate investment see Hubbard (1998).

separately from one another, the main reason being the consolidated government budget constraint. From an optimal taxation perspective,[12] the literature on optimal policy can broadly be classified according to two criteria. The first one relates to restrictions of the set of instruments available to a policy maker and differentiates the Ramsey approach from the Mirrlees (1971) approach to optimal taxation. The solution to an optimal policy problem from a Ramsey perspective is restricted due to the policy maker having access only to distortionary instruments, thus ruling out lump-sum taxes. Conversely, the Mirrlees approach does not restrict the set of policy instruments in an ad hoc way, but starts from informational frictions which endogenously restrict the set of instruments implementing the optimal allocation. In any case, for an allocation to be implementable, it must be possible to decentralize the allocation as a competetive equilibrium, given the planner's restrictions on disposable instruments and information; this means that implementability and, where applicable, incentive-compatibility constraints need to be respected. The reformulation of the policy problem in terms of these restrictions on the set of allocations which can be implemented as a competitive equilibrium is called a primal approach. The second classification criterion relates to the question of whether policy makers have access to a commitment technology in the sense of being able to make intertemporally binding policy choices. This question is of central importance if optimal policies are dynamically inconsistent, i.e. in situations where a sequential policy maker who reconsiders a previously announced optimal policy plan faces incentives to revise her choices. Indeed, it is a pervasive feature of dynamic models of optimal policy making that socially desirable policies may suffer from a lack of credibility. Specifically, absent a commitment technology the prediction is that such policies cannot be implemented because the costs of policy decisions are not fully internalized by the policy maker. The well-known reason behind this time inconsistency problem is that a sequential decision maker, in taking private expectations as given, neglects the influence of her current policy choices on the past formation of the public's forward-looking expectations. Optimal policies implemented under commitment are called Ramsey policies. The relevant protocol for optimal policies without commitment depends on how precisely the history of past behavior impinges on current agents' strategies, i.e. the analysis needs to be formalized as a dynamic game. If the class of admissible strategies is reputation-free and restricted to map-

[12]For a review of the literature as well as an exposition of the methodology see Chari and Kehoe (1998). There is a closely related branch of the literature which frames optimal policy problems in terms of stabilization policies in response to stochastic shocks hitting an economy subject to a set of frictions such as price stickiness and monopolistic competition. The main concern there is to investigate how optimal policies (within a restricted class) depend on the type of shocks affecting the economy as well as to design policies such as to rule out indeterminacy of equilibria. Compare Schmitt-Grohé and Uribe (2004, 2006) for important examples of the two strands of the literature in the context of monetary and fiscal policies.

pings whereby the past influences the current play only through its effect on a set of endogenous state variables, which summarize the direct effect of the past on the current environment, the relevant equilibrium concept is Markovian.[13]

The policy problems posed in chapters one and two are set up in the tradition of the Ramsey (as opposed to the Mirrlees) literature as far as the assumptions on the information and the set of instruments available to policy makers is concerned. However, considering an environment where there is no explicit commitment technology, the chapters focus on sequential implementation of policies, whereby an equilibrium under optimal policy obtains as a Markov-perfect equilibrium (as opposed to a Ramsey equilibrium).[14] Against this background, an important innovation proposed there is to take prevailing policy institutions seriously and to consider optimal policies implemented not by a ficticious monolithic policy maker controlling the complete set of available instruments, but by a sequence of pairs of interacting policy makers who are each independently commissioned with the conduct of monetary and fiscal policy, respectively. This highlights an important aspect of monetary-fiscal interactions, which has not yet been addressed in the existing literature on optimal macroeconomic policies because it either proceeds under a monolithic agency assumption or dichotomizes the relevant policy problems.

Monetary-fiscal interactions and government debt: The fact that monetary and fiscal policies are interdependet with respect to their effects on the economy is well-recognized. In their unpleasant monetarist arithmetic, Sargent and Wallace (1981) demonstrate the importance of the intertemporal government budget constraint and hence the role of fiscal policy for the determination of the inflationary consequences of monetary policies. At the same time, the authors stress that the conclusions to be drawn from a joint analysis of monetary and fiscal policies crucially depend on the assumptions about the applicability of certain policy regimes. These propositions have been taken up by the fiscal theory of the price level as developed by, among others, Leeper (1991), Sims (1994) and Woodford (1994). The basic tenet of this theory is that a change in a dynamic fiscal policy, organizing a debt-financed tax cut today under the maintained unconditional commitment to a given sequence of future primary budget deficits, induces wealth effects which trigger an adjustment of the current price level to restore an equilibrium. The theoretical foundation underlying this mechanism is controversial. Moreover, it is not clear whether the policies needed to generate fiscalist dynamics can be rationalized as part of an optimal government plan. Models of optimal policy, endogenizing monetary and

[13] Alternatively, allowing for reputational mechanisms, the analysis can be cast within the framework of sustainable plans (Chari and Kehoe, 1990) or more general techniques for solving repeated games (Abreu, Pearce and Stacchetti, 1990).

[14] In contrast, chapter three does not pursue a normative, but a positive agenda.

fiscal policy choices as the result of explicit optimization exercises with well-defined constraints, lend themselves to analyze these questions. However, a drawback with these contributions is that they generally start from the assumption that there is only one entity which effectively decides about the complete set of policy instruments. Alternatively, when the focus of the analysis is on monetary (fiscal) policy, it is essentially assumed that fiscal (monetary) policy is absent or exogenously given to the model. Consequently, such approaches offer only limited insights into dynamic monetary-fiscal interactions. Therefore, it is important to understand (i) how and (ii) which policies are implemented under the decentralized authority of interacting and sequentially optimizing policy makers; the first two chapters of this dissertation are concerened with precisely this exercise for two different economic environments.

Against this background, the dynamic evolution of government debt plays a crucial role because the intertemporal government budget constraint, which keeps track of the indebtedness of the public sector against the private sector, consolidates the budgets of monetary and fiscal authorities. Hence, government debt is both an important primitive for the determination of macroeconomic policy choices and a source of interdependence between monetary and fiscal policies.[15] Indeed, the arguments put forward in the unpleasant monetarist arithmetic and the fiscal theory of the price level hinge on the existence of outstanding government debt. Moreover, in stochastic environments government debt constitutes an important device for insuring against macroeconomic (e.g. budgetary) and idiosyncratic risks, i.e. it serves as a cyclical shock absorber.[16] In this context, an important consideration is the fact that government debt is generally issued in nominal terms.[17] On the one hand, the real ex-post returns on nominal bonds can be made state contingent by engineering appropriate changes in the price level; hence, even if the government is constrained

[15] In their review on government debt, Elmendorf and Mankiw (1999) argue that, apart from its short-run effects on aggregate demand if Ricardian equivalence fails to hold and its long-run effects on capital accumulation (Diamond, 1965), government debt affects the economy also via the following economic mechanisms: (i) it can affect monetary policy; (ii) it gives rise to a deadweight loss due to the taxes needed to service public liabilities; (iii) it alters the political process that determines fiscal policy; (iv) it may make the economy more vulnerable to confidence crises and impose further constraints on policies.

[16] As regards aggregate risk, the main arguments evolve around the opportunity of tax smoothing in the face of shocks to aggregate productivity and government expenditures; compare Barro (1979), Lucas and Stokey (1983) or Aiyagari et al. (2002). Insurance against idiosyncratic risks plays a role in incomplete markets environments, where government debt facilitates precautionary savings or helps to relax incentive problems; compare e.g. Aiyagari and McGrattan (1998) or Holmström and Tirole (1998). Shin (2006) provides a synthesis in terms of competing private and public insurance motives.

[17] At the end of 2003, the ratio of central government debt to GDP was 38.8% in Germany, 24.7% in Mexico, 40.1% in the UK and 35.3% in the US; for the same countries, the share of index-linked bonds in total bonds amounted to 0.0%, 6.8%, 24.0% and 6.5%, respectively, the remainder being nominal non state contingent bonds; compare OECD (2005).

to issue nominally risk-free bonds, monetary policy can be used to complete markets by appropriately taxing the returns on nominal government debt.[18] On the other hand, since outstanding government debt in nominal denomination constitutes an inelastic tax base, sequentially optimizing policy makers will generally face incentives to relax their debt burden by eroding the real value of their liabilities through the inflation tax; in other words, nominal government debt is the source of a time consistency problem.

A recurring theme regarding the optimal conduct of monetary policy is the Friedman (1969) rule, i.e. the prescription of zero nominal interest rates in order to minimze the deadweight loss due to the implicit tax on consumption.[19] However, Díaz-Giménez et al. (2006) point out the difficulty of credibly implementing such a policy in economies with outstanding nominal government debt because of the temptation to inflate in order to reduce the real value of the liabilities. Following ideas evolving around managing the maturity structure of government debt in a way such as to make markets complete even with non-contingent debt,[20] there have been proposals to overcome the time consistency problem caused by the existence of nominal government debt. In particular, Alvarez, Kehoe and Neumeyer (2004) consider a variety of monetary models and show that, if the optimal monetary policy under commitment is to follow the Friedman rule, then the time consistency problem can be solved by issuing a mixture of nominal and real (indexed) bonds in a way such that the present value of nominal claims is zero.[21] The first chapter in this dissertation shows that the decentralization of decision authority between monetary and fiscal policy makers may be another possibility to achieve this objective; there, what helps to sustain non-inflationary equilibria is a coordination failure among monetary and fiscal policy makers. Against the background of the empirical fact of substantial amounts of nominal government liabilities (cf. fn. 16 for data on a set of OECD countries), this is an important result.

Dynamic general equilibrium: It has been argued above that the problems addressed in this dissertation blend normative and positive aspects. Especially the normative and quantitative dimensions of this program make it necessary to consider microfounded dynamic general equilibrium models rather than ad hoc specifications of reduced forms. While this comes at some cost in terms of modeling effort, there are a number of decisive advantages. First of all, models cast in a dynamic general

[18]Compare Chari, Christiano and Kehoe (1991).

[19]Chari, Christiano and Kehoe (1996) identify sufficient conditions for the optimality of the Friedman rule and relate their results to principles of optimal taxation.

[20]See Angeletos (2002) and Buera and Nicolini (2004).

[21]Persson, Persson and Svensson (2006) generalize this result to an economy where the Friedman rule is not optimal. Alternative approaches to overcome of mitigate monetary time consistency problems are reviewed in chapters one and two.

equilibrium framework allow to investigate the pertinent quantitative implications in greater detail and hence generate more robust empirical predictions. This is for a variety of reasons. Most importantly, a dynamic general equilibrium framework is indispensable to understand the formation and role of intertemporal prices such as real and nominal interest rates and their interplay with agents' dynamic decisions with respect to the intertemporal accumulation of real or financial wealth in the form of physical capital, money, bonds or other assets. In particular, dynamic general equilibrium models comprise explicitly forward-looking behavior of all economic agents; hence, current equilibrium outcomes are influenced by expectations with respect to the future. To the extent that macroeconomic policies implemented in the future affect the ensuing set of allocations and prices, this is incorporated into the formation of rational expectations. On the other hand, which set of policies is optimal from a government authority's perspective generally depends on the public's expectations formed in the past. This reasoning illustrates that, for many macroeconomic policy problems, a well-defined concept for economic welfare, deriving from first principles rather than a postulated loss function, is inherently dynamic.[22] Similarly, the formulation of optimal policy problems based on reduced forms in general or linear-quadratic approximations in particular may result in misleading conclusions because often (or by construction in case of a linear-quadratic setup) the prediction is a unique equilibrium, whereas the true model allows for multiple equilibria.[23] The point is that the nonlinearities implied by a general equilibrium economy subject to endogenous policies may provide scope for (additional) self-fulfilling feedback mechanisms. Expectation traps, i.e. situations where a change in agents' expectations induces them to take "defensive actions" which, in turn, trap the policy maker into accommodating the change in expectations, are an instance of such equilibrium multiplicity.[24]

These arguments forcefully underpin the necessity of a dynamic general equilibrium setup to meaningfully investigate the determination of macroeconomic policies and the way they interact with the economy. *A fortiori*, this is true for the analyis of the interaction among distinct macroeconomic policymakers (chapters one and two) and the interaction of government policies with specific contract relationships

[22]For an instructive example clarifying what can go wrong when a dynamic policy problem is represented in terms of a (sequence of) static loss function(s), see the discussion of Krugman (1996) by Kehoe (1996).

[23]It is important to distinguish this concept of multiplicity (of locally unique equilibria) from the notion of local indeterminacy of rational expectations equilibria. Compare King and Wolman (2004) for an excellent discussion.

[24]In the context of monetary policy, an interesting example for a diverging pattern of predictions depending on the respective model specification can be obtained by comparing the linear-quadratic setup in Barro and Gordon (1983a,b) with its generalization to a full general equilibrium economy in Albanesi, Chari and Christiano (2001, 2003); other examples include Calvo (1988), King and Wolman (2004) and Siu (2005).

among private agents (chapter three). It is for these reasons that the chapters of this dissertation all share the principle that they embed a set of game-theoretic and contract-theoretic bulding blocks into fully articulated dynamic general equilibrium economies rather than working out their implications in isolation.

In the next section, we summarize the contents and contributions of the individual chapters in this dissertation. Chapters one and two are concerned with problems of dynamic monetary-fiscal interactions, whereas chapter three considers the interplay between monetary policy and financial markets' capacity to provide liquidity to the productive sector as well as the pertinent implications for an economy's aggregate productivity.

Chapter summaries

Chapter one: The first chapter reconsiders the problem of the dynamic inconsistency of optimal policies on the basis of a deterministic model formalizing the interaction of monetary and fiscal policies. Drawing on Lucas and Stokey (1983), the environment is a monetary production economy with nominal government debt, but without physical capital. The government sector, consisting of a fiscal and a monetary authority who interact subject to a consolidated government budget constraint, faces the task of optimally financing an exogenous sequence of public expenditures. The sources of revenue are a linear consumption tax as well as seignorage from inflationary monetary expansions; since money is required to purchase goods, both of these instruments are distortionary. However, given that government debt is issued in nominal terms, the inflationary distortions introduced by monetary policy have the additional effect of deflating the real value of the outstanding government liabilities. Under *single agency*, the situation considered by orthodox optimal taxation models, this makes it attractive for a benevolent planner to create inflation because the latter lump-sum aspect of the inflation tax allows to economize on future distortionary taxation. The result is a time consistency problem, whereby in equilibrium the public correctly anticipates the policy maker's incentive to generate unanticipated expansions, thus increasing the interest rate costs of outstanding debt even if there are no unanticipated inflation episodes. Since non-inflationary policies cannot be credibly implemented, there is an inflation bias,[25] and from this perspective nominal government debt constitutes a burden on monetary policy. Consequently, absent a commitment technology, the optimal sequential policy is to progressively deplete the outstanding stock of debt until the extra liability costs vanish.

Against this background, we argue that above reasoning critically hinges on

[25] Here, and in what follows, inflation bias refers to a situation where the rate of money growth is systematically related to the stock of real government debt.

the assumption that there is only a single monolithic policy maker who controls the complete set of available policy instruments. For that purpose, the policy problem described above is recast in a way such that both the fiscal authority and an independent central bank do implement their respective policies separately from one another. In contrast, the assumption that there is no intertemporal commitment technology is maintained. This means that the authorities interact strategically in a dynamic game, where - because it shapes the monetary incentives to create inflation - a measure of the real debt burden inherited from the past takes the role of the decisive state variable. Now, employing game-theoretic tools, we (i) establish the existence of a Markov-perfect equilibrium under *decentralized authority* and (ii) analyze its key properties. Of central interest is the finding that the separation of decision power among the two authorities can eliminate the inflation bias and make the optimal policies under sequential implementation time consistent. The reason for this is that the fiscal authority's policy choices give rise to an additional constraint faced by the monetary authority in that now the distortions imposed by the fiscal consumption tax cannot be substituted away by means of a monetary expansion. Formally, this is an instance of coordination failure, and the consequence is that the monetary time consistency problem may vanish even for positive amounts of public liabilities such that a non-inflationary policy can be credibly implemented. However, this favorable result is conditional on a fiscal policy keeping the stock of real government debt constant. In detail, decentralized authority allows for the emergence of multiple equilibria. Specifically, a first equilibrium, called *quasi-single agency equilibrium*, perfectly replicates the allocation implemented by a monolithic sequential policy maker controlling the complete set of monetary and fiscal instruments. Here, monetary policy is always marginally responsive to the real value of outstanding liabilities. Additionally, there is another equilibrium, denoted *quasi-indexation equilibrium*, which implements the allocation otherwise attainable only in an economy with indexed debt. With indexed debt, there is no time consistency problem by construction; it follows that decentralized authority provides scope for overcoming the time consistency problem: Monetary policy is no longer systematically related to the real value of the stock of debt, and fiscal policy imposes taxes such as to keep the level of real debt constant ("balance the budget"). Although the two equilibria can be ranked in welfare terms, we do not offer a strong equilibrium selection argument. What can be said, though, is that fiscal behavior is a decisive determinant of the incentives faced by the monetary authority. In this sense, inflation is to be seen as a fiscal phenomenon.

Chapter two: The next chapter further elaborates on the this conclusion and argues that the long-term level of public liabilities and inflation can be explained as the endogenous outcome of a dynamic game played between the interacting fiscal and monetary policy authorities. Specifically, the benchmark model from the first chapter is perturbed in that (i) the central bank is assumed to be "conservative" in the sense of attaching excessive weight on an inflationary loss term and (ii) the fiscal authority is modelled as "impatient" in the sense of discounting future payoffs at a higher rate that the public does. These modifications are best understood in the light of politico-economic considerations, and, importantly, do reflect empirically relevant institutions such as the expressed concern for price stability in many central bank statutes. Thus, the chapter's principal objective is to provide a positive theory of the dynamics of government debt and inflation. The key implication of the assumption of fiscal impatience is that the conduct of fiscal policy is characterized by a tendency to accumulate public debt. This means that the monetary authority faces a situation where the fiscal policy maker is unwilling to periodically balance the budget. The consequence is that the monetary incentives to create inflation necessarily reappear, thus eliminating the favorable quasi-indexation equilibrium existing in the unperturbed setup of chapter one. The equilibrium outcome of the dynamic game is a path of real debt converging to a finite positive level and associated with a steady state inflation bias. Two conclusions can be drawn: First, the inflation bias is the result of the fiscal authority gaining leverage also over the nominal properties of the equilibrium allocation. Therefore, the model can be seen as providing a game-theoretic foundation for the propositions made in the fiscal theory of the price level; importantly, however, the mechanics generating fiscalist equilibrium outcomes are driven by the sequential optimality of the authorities' policy choices rather than perceived wealth effects of private agents and are therefore different from those proposed in the fiscal theory itself. Specifically, the fiscal authority has the power to reject certain (classes of) equilibria,[26] while the monetary authority is always marginally responsive to the stock of debt. Second, variations in the two critical parameters, the degrees of monetary conservatism and fiscal impatience, respectively, lead to the interesting observation that increased monetary conservatism, i.e. a higher weight on the inflationary loss term in the monetary authority's objective function, may have adverse welfare implications. The reason for this is that increased inflation aversion gives rise to a superior, but still incomplete commitment capacity not to engage in inflationary expansions. While this direct effect is desirable, there is also an indirect strategic effect with adverse consequences: The monetary authority's increased conservatism implies that any given level of real government debt can be sustained at a lower inflation rate. Since the fiscal authority, despite its relative impatience, also cares about the economy's future performance and hence about future inflation, it issues more debt the more inflation averse the central bank is. This debt has to be serviced by

[26]On this point, compare e.g. Kocherlakota and Phelan (1999) or Bassetto (2002, 2005).

means of distortionary government activity, crowds out private consumption and results in lower welfare.

Conceptually, the main innovation of the framework underlying the first two chapters is to formalize the problem of dynamic monetary-fiscal interactions from a game-theoretic perspective. The central question asked is: What is the nature of optimal monetary and fiscal policies if interacting policy makers decide on their respective instruments in a decentralized fashion? This question also motivates the key modification of the modelling approach, which differentiates the approach from conventional models of optimal macroeconomic policy and reflects the institutional provisions observed in most advanced economies, namely that monetary and fiscal policies are generally implemented by distinct and autonomous authorities. Formally, this converts the dynamic optimal taxation setup into a dynamic game. Throughout, the focus is on sequentially optimal policies without commitment, which further complicates the analysis because, in addition to the respective opponent's play, each policy maker has to take into account also the forward-looking formation of private expectations. Critical in this context is that the game is not of a simple repeated variety, but features an endogenous state variable (a measure of the real value of inherited public liabilities). Abstracting from reputational effects, the focus is on Markov-perfect equilibrium strategies and outcomes.[27] Then each policy authority's calculus comprises both the effects of the respective policy choice on current payoffs and the effects from strategically manipulating the endogenous state variable because the latter shapes the incentives faced by future policy makers. Methodologically, the analysis builds on a solution procedure proposed by Klein, Quadrini and Ríos-Rull (2005), which is modified to accommodate multiple policy makers solving their primal policy problems over the same allocation. Chapter one proves existence of a Markov-perfect equilibrium, which is of some importance since so far the knowledge about the structure of policy games in general equilibrium economies is limited. The qualitative characterization of the equilibrium outcomes proceeds via first order conditions with a neat economic interpretation; quantitatively, the explicit solution for equilibrium outcomes relies on numerical methods. The setup does not lend itself to a linear-quadratic approximation or, more generally, any local solution method. The reason is that the application of local approximation methods requires knowledge about the steady state, which is not available before the policy game is not solved;

[27] The justification for this restriction on the set of admissible strategies is that Markovian equilibria are self-reinforcing in a natural way (the best response to a Markov strategy is again a Markov strategy) and that they hinge on minimal informational requirements. Moreover, because history does not matter except for its direct influence transmitted via the inherited endogenous state variable, Markov equilibria have very clear-cut equilibrium predictions and, if differentiable, are numerically relatively tractable.

moreover, as argued above, linear-quadratic methods may fail to detect equilibrium multiplicity. Therefore, as advocated by Judd (1998), the numerical analysis applies global projection methods, here a collocation on a one-dimensional state space.

Chapter three: The third chapter has a different focus. It employs a dynamic stochastic general equilibrium model with a financial market friction to rationalize the empirically observed negative relationship between inflation and total factor productivity (TFP).[28] Specifically, an empirical inspection of US data establishes that, at business cycle (i.e. quarterly and yearly) frequencies, there is a negative causal effect of inflation on aggregate productivity; conversely, inflation is found to be exogenous with respect to aggregate productivity. This latter piece of information is important since it is at odds with the argument that negative supply shocks are the principal reason for why inflation and aggregate productivity are negatively related over the cycle. Against this background, we put forward the hypothesis that the interaction between monetary policy and financial markets' capacity to intermediate scarce liquidity is an important factor which helps to explain the empirical evidence. For that purpose, rather than taking the productivity process as exogenous, we set up a model featuring an endogenous component of aggregate productivity. This is achieved by allowing for endogenous technology choice on behalf of entrepreneurial firms subject to idiosyncratic liquidity shocks, whereby a moral hazard problem in the spirit of Holmström and Tirole (1998) prevents complete insurance against this risk. In detail, firms' physical investment can be channelled into two different technologies: a safe, but return-dominated "basic" technology and an "advanced" technology yielding higher expected returns, but subject to liquidity risk.[29] Firms can hold a buffer stock of readily marketable assets to partially insure their advanced activities, but this comes at the cost of a liquidity premium. In the model, this liquidity premium coincides with the nominal interest rate. Given the underlying limited participation structure, monetary policy affects nominal interest rates in two ways: (i) systematically, because higher rates of money growth feed into higher nominal interest rates, and (ii) on impact, because unexpected monetary expansions have a liquidity effect. In this environment, the model demonstrates how nominal interest rate distortions influence not only the overall amount, but also the qualitative composition of aggregate investment. The transmission mechanism is shown to hinge on the differential importance of holding costly liquidity across the set of available technologies; hence, there results an investment composition effect triggered by variations in monetary policy. At the level of an aggregate production function, understood as an equilibrium relationship mapping aggregate inputs into

[28]Here, and in what follows, TFP is to be understood as the Solow residual generated from a calibrated aggregate production function employing capital and effective labor.

[29]For a similar setup, compare Aghion et al. (2006).

aggregate output, this means that shocks to monetary policy and aggregate productivity are not orthogonal; in contrast, there is a systematic negative supply-side effect of inflation on aggregate productivity.

In summary, the theoretical model makes a number of empirical predictions linking the adverse effects of inflation to nominal interest rate distortions which, by increasing the costs of corporate liquidity holdings, shift the composition of aggregate investment towards less productive activities. As a first step, in order to gain insights with respect to the quantitative importance of these effects, the model is calibrated to US business cycle data and then subjected to a number of numerical experiments; the pertinent findings further corroborate the conclusion that monetary policy shocks can account for a significant proportion of the variation in TFP. Moreover, we complement the empirical results relating to US aggregate data on inflation and TFP by a detailed analysis of disaggregate industry-level and firm-level panel data. This analysis provides comprehensive evidence consistent with (i) the implications of constrained-efficient contracting with respect to the postulated agency problem, (ii) the notion that liquidity risk is indeed concentrated in industrial sectors which are relatively exposed to advanced technologies, as well as (iii) the hypothesis that corporate liquidity holdings are used as a precautionary buffer stock to hedge investment into advanced technologies (as proxied by firm level R&D expenditures). In addition, the scope of such insurance is negatively affected by the level of inflation and, as predicted by the model, depends on a set of industry-level characteristics. Overall, we view the empirical evidence as strongly supportive of the particular theory proposed in the theoretical model.

The main contribution of chapter three is an empirical one. On the theoretical side, it embeds the contracting problem due to Homström and Tirole (1998) into a dynamic stochastic general equilibrium model. This facilitates the derivation of some higher-order implications of the contracting scheme which are driven by general equilibrium effects. Moreover, the model's structure is exploited as an explicit device to aggregate quantities from the menue of available technology into an implied aggregate production function. These aspects make the underlying monetary business cycle model a coherent system within which the theoretical arguments are formalized. Turning to the chapter's empirical perspective, we address the following set of questions: What is the relation between inflation and aggregate productivity? Which role does monetary policy play for the determination of aggregate productivity? How do nominal distortions affect the allocation of firms' physical investment? Utilizing dynamic panel estimation methods due to Arellano and Bond (1991) and Blundell and Bond (1998), we investigate these questions on the basis of panel data at different levels of aggregation. Relying on instruments whose validity is testable, this approach allows for identification of causal effects rather than mere correlations. As hinted above, the evidence emerging from the panel regressions is consistent with the theoretically postulated chain running from inflation over corporate liquidity demand and the composition of physical investment to the evolution of aggregate productivity.

This introductory preview has summarized the contents of the chapters following below; it has emphasized a number of overarching themes that the individual approaches have in common. A short concluding chapter will take up a number of these issues again. Notwithstanding, the following three chapters are each devised as independent, self-contained units.

Chapter 1

On the Time Consistency of Optimal Policies with Interacting Authorities

1.1 Introduction

The issue of the credibility of macroeconomic policies has been first analyzed from a formal perspective by Kydland and Prescott (1977) and Calvo (1978). In the subsequent literature, it has turned out as a pervasive feature of dynamic models of optimal policy making that desirable policies may suffer from a lack of credibility when the policy maker cannot command a non-distortionary policy instrument. In such environments, the socially optimal policy in the absence of ex-post incentive constraints generally yields a second best outcome. However, if the policy maker does not have access to a commitment technology, the prediction is that such second best policies cannot be implemented because the costs of policy decisions are not fully internalized by the policy maker. The well-known reason behind this time consistency problem is that a sequential decision maker, in taking private expectations as given, neglects the influence of his current policy choices on the past formation of the public's forward-looking expectations. The problem of time inconsistency can then be dealt with in several ways. The ideas generally evolve around introducing some form of indirect commitment through the design of appropriate institutions like rules, contracts, delegation or a richer set of policy instruments with built-in irreversibilites. With an infinite time horizon, another way to reach "good" outcomes even without commitment is to rely on reputational mechanisms. For example, Barro and Gordon (1983b) have illustrated in a repeated setting how reputational forces can substitute for formal rules by constructing a policy equilibrium where a simple trigger strategy governs the public's formation of expectations.

In the present paper, we explicitly acknowledge the fact that policies are implemented sequentially and assume that (i) a commitment technology is not available and that (ii) reputational mechanisms are not at work. We then identify a new mechanism which can help to overcome the time consistency problem faced by a single decision making unit. Specifically, we show how the decentralization of decision authority over the available policy instruments among interacting policy makers can change the latters' dynamic incentive constraints in a way that eliminates the temptation to surprise the public. It is worthwhile to stress that our concept of decentralization does not employ reputation or other history-dependent punishment mechanisms. While our results are derived in the context of a particular model, we believe that the identified mechanism has more general relevance.

The model framework considered is a simple monetary dynamic general equilibrium economy without capital, as introduced by Lucas and Stokey (1983). In such an economy, Díaz-Giménez et al. (2006) analyze from an optimal taxation perspective the dynamic distortions that are caused by outstanding nominal government debt. With a particular specification of preferences,[1] their central findings for the case of a monolithic single policy maker who controls both monetary and fiscal policy instruments are the following: With nominal one-period debt (and unindexed bonds), there is an incentive to reduce the stock of debt through unanticipated inflation because the lump-sum aspect of the inflation tax allows to economize on distortionary taxation; this creates the standard time inconsistency problem. In the rational expectations equilibrium, the ex-post incentive to generate inflation increases the costs of outstanding debt even if there are no unanticipated inflation episodes. Therefore, the optimal policy under sequential choice and no commitment is to progressively deplete the outstanding stock of debt until the extra liability costs vanish. The authors' general message thus is that, with nominal debt and sequential policy making, the optimal policy (inflation) will not only depend on elasticities as in a standard model of Ramsey-optimal taxation, but also on the marginal gain from changing the real value of the existing debt.

In the present paper, we reconsider this dynamic policy making problem from a strategic perspective with interaction between monetary and fiscal policy. This makes it necessary to resort to game-theoretic methods. Since our starting point is that reputational mechanisms cannot be relied upon, a natural way to analyze the dynamic evolution of the economy is to consider Markov-perfect equilibria (MPE) only. With this class of strategies, the past influences the current play only through its effect on a set of state variables which summarize the direct effect of the past on the current environment. While the restriction to MPE comes at the cost of not being able to identify all equilibria that can possibly be sustained (e.g. by means of history-dependent reputational mechanisms), it has the advantage of imposing

[1] Martin (2006) generalizes the results obtained by Díaz-Giménez et al. (2006); we will return to this issue below.

only minimal informational requirements on the policy makers and of facilitating the identification of differentiable equilibria by first order conditions which allow for a straightforward economic interpretation.

Our model setup differs from a standard model of optimal policy only along one dimension, namely the introduction of a second policy authority. Given the institutional provisions prevailing in most advanced economies, we see the assumption of two interacting policy authorities who take their decisions independently, but subject to a consolidated government budget constraint as a realistic one. Nevertheless, the paper's main point is of a conceptual nature. Starting from the results in Díaz-Giménez et al. (2006), we deal with the case of a dynamic game where policies are implemented sequentially, but, in each period, the two authorities move simultaneously. The key finding is that with decentralized authority over the relevant policy instruments, the supply of money balances and a linear consumption tax, there is scope for coordinating private expectations in a favorable way. Specifically, the MPE allocation from the case of a single policy maker is no longer the only equilibrium outcome, and the previously identified inflation bias may vanish even for positive levels of outstanding government debt. With such multiplicity of equilibria, expectations about the future play are key to pin down current policy choices. The presence of an independent fiscal authority lacking access to a non-distortionary policy instrument introduces an additional constraint on implementable allocations faced by the monetary policy maker; the reason is that the current fiscal policy needs to be taken as given rather than as a free choice variable. Hence, unlike the standard setup where a monolithic sequential policy maker uses the inflation tax to substitute for the fiscal consumption tax, under interaction it is the case that distortions introduced by the current fiscal play cannot be removed. The consequence is that the welfare costs of imposing on private agents the inflation tax in addition to the fiscal consumption tax may become excessively high. Therefore, private expectations about a continuation play not subject to an inflation bias become rational. And given such expectations, there is room for current policies generating enough fiscal revenue to keep the level of government debt constant without recurring to the inflation tax. Hence, besides the single-agency equilibrium described in Díaz-Giménez et al. (2006) there exists also a MPE where the associated dynamically consistent policies implement a true second best outcome. Thus, while the established view from the public finance literature suggests that fiscal (mis)behavior may contribute to the monetary time consistency problem, this paper highlights a mechanism working in the opposite direction: It is precisely the presence of a dynamically optimizing fiscal authority which may help to put discipline on the monetary authority's dynamic choices.

The rest of the paper is organized as follows. The following section sets up the model and defines a competitive equilibrium for our economy. Then, section 3 lays out the structure of the policy game between the monetary and the fiscal authority.

Section 4 briefly comments on the solution strategy to find the MPE, before the subsequent section establishes the existence of a MPE and describes the equilibrium outcomes. Finally, the paper concludes with a review of the related literature and some further remarks. Technical details are relegated to the Appendix.

1.2 The model

The object of our analysis is a monetary dynamic general equilibrium model economy which is made up of a government sector and a private sector. As in Lucas and Stokey (1983) there is no capital. The government sector consists of a monetary authority and a fiscal authority who take their decisions independently. The fiscal authority collects consumption taxes[2] τ_t^c in order to finance an exogenously given stream of public expenditures g_t. For the time being, we let $g_t = g$ be deterministic and constant over time. The policy instrument controlled by the monetary authority is the supply of money M_{t+1}^g (the superscript g is used to distinguish an aggregate variable from an individual variable where necessary), whereby seignorage revenues from money creation $M_{t+1}^g - M_t^g$ are used to purchase g from the private households. Hence, the two government authorities interact via a consolidated government budget constraint, but decision power remains decentralized among the two independent institutions. Finally, we assume that the fiscal authority, besides its tax policy, issues nominal one-period bonds B_{t+1}^g, whereby the quantity of bonds traded is determined by the following flow budget constraint for the government sector which has to be satisfied for all $t \geq 0$:

$$M_{t+1}^g + B_{t+1}^g + P_t \tau_t^c c_t \geq M_t^g + B_t^g(1 + R_t) + P_t g \tag{1.1}$$

Here, P_t is the price level prevailing at time t, while R_t is the nominal interest rate paid on the bonds issued at date $t-1$. The initial stock of money M_0^g and the initial debt liabilities $B_0^g(1+R_0)$ are given. However, we will impose the additional consistency condition that, in the rational expectations equilibrium, there is no surprise inflation in the initial ($t = 0$) period; thus, by linking the nominal interest rate R_0 to the equilibrium rate of inflation in the first period, we prevent the authorities from taking advantage of the inelasticity of the amount of oustanding nominal balances M_0 and B_0 in the initial period.

On the private side, the economy is inhabited by a continuum of identical infinitely-lived households whose preferences over sequences of consumption c_t and

[2] An alternative specification would be to use labor taxation, τ_t^n. However, against the background of the general equivalence results for different forms of taxation, the choice of the tax instrument assigned to the fiscal authority is irrelevant so that our specification is without loss of generality.

labor n_t can be represented by the following additively-separable expression:

$$\sum_{t=0}^{\infty} \beta^t \{u(c_t) - v(n_t)\}, \quad (1.2)$$

where the discount factor β satisfies $0 < \beta < 1$. In what follows, we will assume $u(c_t) = log(c_t)$ and $v(n_t) = \alpha n_t$.[3] Each consumer faces the following sequence of budget constraints:

$$M_{t+1} + B_{t+1} \leq M_t - P_t(1 + \tau_t^c)c_t + B_t(1 + R_t) + W_t n_t, \quad (1.3)$$

where W_t is the nominal wage and B_{t+1} and M_{t+1} are nominal government debt and nominal money balances taken over from period t to period $t+1$. We assume that each consumer faces a no-Ponzi condition that prevents him from running explosive consumption/debt schemes:

$$lim_{T\to\infty} \beta^T \frac{B_{T+1}}{P_T} \geq 0 \quad (1.4)$$

As a shortcut for introducing a well-defined money demand we additionally assume that the gross-of-tax consumption expenditure in period t must be financed using currency carried over from period $t-1$, which implies the following cash-in-advance (CIA) constraint:

$$M_t \geq P_t(1 + \tau_t^c)c_t \quad (1.5)$$

The timing structure underlying this CIA constraint follows Svensson (1985). Specifically, we assume that newly injected money transfers are not available for purchasing private consumption until the next period. Consequently, the purchases of goods have to be undertaken before nominal balances can be reshuffled optimally, and the CIA constraint may not allow to realize the desired consumption. Moreover, the information about the money injection leads to an immediate price reaction. Hence, the effects of inflation are twofold: First, expected inflation leads to a distortion via its effect on the nominal interest rate. Second, surprise inflation is distortionary since the households are constrained in their consumption decisions by the value of

[3]The assumption of linear disutility of labor is made to sharpen the discussion, but implies also that the government sector cannot affect the real interest rate. Conversely, the assumption of log utility from consumption allows to focus on the role of nominal debt as a source of time inconsistency rather than on the effects due to private holdings of nominal money balances. That is, we abstract from seignorage on base money and focus on the implications of changing the real value of nominal debt. Importantly, this focus is consistent with the situation in most developed economies where government debt is arguably more important than money holdings as a source of dynamically inconsistent incentives. See also Nicolini (1998) for an instructive exposition of the nature of the time inconsistency of monetary policy and Martin (2006) for results with a more general specification of preferences.

the money balances taken over from the previous period.[4] Importantly, therefore, monetary policy has wealth effects and is not neutral. For a benevolent monetary authority this means that it trades off the reduction in the households' current utility and the increase in future utility which results from the reduction in future distortions when it considers whether or not to carry out a surprise inflation.

The productive side of the model economy is extremely simple since there is no capital. In each period, labor n_t can be transformed into private consumption c_t or public consumption g at a constant rate, which we assume to be one. Then, the equilibrium real wage is $w_t \equiv \frac{W_t}{P_t} = 1$ for all $t \geq 0$, and aggregate feasibility is reflected by the following linear resource constraint:

$$c_t + g \leq n_t \tag{1.6}$$

We are now ready to define a competitive equilibrium for given government policy choices $\{\tau_t^c, M_{t+1}^g, B_{t+1}^g, g\}_{t=0}^{\infty}$.

Definition 1.1 *A competitive equilibrium for this economy is composed of the government sector's policies* $\{\tau_t^c, M_{t+1}^g, B_{t+1}^g, g\}_{t=0}^{\infty}$*, an allocation* $\{c_t, n_t, B_{t+1}, M_{t+1}\}_{t=0}^{\infty}$*, and prices* $\{R_{t+1}, P_t\}_{t=0}^{\infty}$ *such that:*

1. *given* $B_0^g(1 + R_0)$ *and* M_0^g*, the policies and the prices satisfy the sequence of budget constraints of the government sector described in expression (1.1);*

2. *when households take* $B_0(1+R_0)$*,* M_0 *and prices as given, the allocation solves the household problem of maximizing (1.2) subject to the private budget constraint (1.3), the CIA constraint (1.5) and the no-Ponzi condition (1.4);*

3. *markets clear, i.e.:* $B_t^g = B_t$*,* $M_t^g = M_t$*, and* g *and the allocation satisfy the economy's resource constraint (1.6) for all* $t \geq 0$*.*

On the basis of our assumptions on household preferences it is straightforward to show that in the competitive equilibrium allocation of this economy the household budget constraint (1.3) and the aggregate resource constraint (1.6) are both satisfied at equality. Moreover, the first order conditions of the Lagrangean representing the household's constrained optimization problem are both necessary and sufficient conditions to characterize the solution to the household problem. Finally, when $R_{t+1} > 0$, the CIA constraint (1.5) is binding, and the competitive equilibrium allocation for given government policies can be determined from the government budget constraint (1.1), the aggregate resource constraint (1.6) and the following conditions that must hold for all $t \geq 0$:

$$M_t = P_t(1 + \tau_t^c)c_t \tag{1.7}$$

[4]This second effect is not present in a CIA economy with the alternative timing structure underlying the model of Lucas and Stokey (1983) where monetary surprises are lump-sum.

$$\frac{u'(c_t)}{v'(n_t)} = (1 + R_t)(1 + \tau_t^c) \tag{1.8}$$

$$(1 + R_{t+1}) = \frac{v'(n_t)}{\beta v'(n_{t+1})} \frac{P_{t+1}}{P_t} \tag{1.9}$$

$$lim_{T \to \infty} \beta^T \frac{M_{T+1} + B_{T+1}}{P_T} = 0 \tag{1.10}$$

1.3 The policy game

Since our focus is on an environment where there is no explicit commitment technology, we now seek to find a time consistent policy rule which is sequentially optimal from the two authorities' perspectives. The sequential decisions about policy are decentralized. In each period, the two authorities move simultaneously and take their respective counterpart's policy choice as well as their successors' future policy mappings as given. We define a policy rule to be the combination of a fiscal and a monetary policy rule; each of these latter rules is determined independently by the subsequent incarnations of the respective authority. We limit the analysis to Markov-stationary policy rules, where a policy rule is a mapping that returns policy choices as a time-invariant function of the current (payoff-relevant) state of the economy. We denote the policy function by $\varphi(z^g) = (\varphi_f(z^g), \varphi_m(z^g))$, where $\varphi_f(z^g)$ and $\varphi_m(z^g)$ are the fiscal and monetary parts of the rule which give the respective policy instruments τ^c and M'^g as functions of the aggregate state $z^g \equiv \frac{B^g(1+R)}{M^g}$, the government sector's real debt burden inherited from the past.[5] In order to identify the equilibrium policy rule, we therefore need to find the optimal time-invariant strategies in the strategic game between the two authorities.

The policy problem in the present economy can be described as an infinite-horizon dynamic game of almost perfect information whose building block is a two-player[6] simultaneous-moves stage game $\mathcal{G}(z_t^g; \varphi) = \Big(f, m; A_f(z_t^g), A_m(z_t^g), \hat{V}(z_t^g; \pi, \varphi), \hat{W}(z_t^g; \pi, \varphi)\Big)$, where z_t^g is the payoff-relevant state variable and π and φ denote arbitrary policy rules in place in the current period (π) and from the next period onwards (φ). We are now going to define the components of the stage game.

As already hinted above, the game is not of a repeated variety due to the presence of the endogenous state variable $z_t^g \equiv \frac{B_t^g(1+R_t)}{M_t^g}$ which can be manipulated over time and is informative about (i) the composition of the nominal claims with which

[5]For most of what follows, we will switch to recursive notation where primes denote variables pertaining to the next time period.

[6]To be precise, we deal with a three-player game where the two policy authorities play in a Stackelberg relation towards the third player, the continuum of private agents. Although an individual household's choices have no strategic weight, their presence - via their formation of expectations - is key to the construction of an equilibrium.

the households enter a given period t and (ii) the real value of the debt burden the government sector inherits from the past. To understand why z_t^g serves as the aggregate state variable, notice that neither nominal variables such as money and bonds nor their real values are sufficient statistics. The reason is that the contemporaneous price level, being endogenous, cannot be used to normalize nominal variables. Moreover, because of the CIA constraint only money, but not the revenue from maturing bonds, is available for current consumption expenditure such that we need information on the composition of the nominal asset portfolio held by private agents. Finally, to appropriately reflect the real debt burden inherited from the past, also the interest payments on maturing bonds must be accounted for.

The players are the fiscal and the monetary authority, indicated by $i = f, m$ respectively. In each period, their actions are $a_f = \tau^c$ and $a_m = M'^g$. The strategy/action spaces[7] for the two players are compact and time-invariant and are given by $A_f(z^g) = [\tau^c_{min}(z^g), \tau^c_{max}(z^g)]$ and $A_m(z^g) = [M'_{min}(z^g), M'_{max}(z^g)]$, where, for all z^g, $\tau^c_{min}(z^g) > -1$, $M'_{min}(z^g) > 0$ and $\tau^c_{max}(z^g), M'_{max}(z^g) < \bar{X}$ for some finite $\bar{X}$. We assume the aggregate state variable z^g to live in a compact interval $I = [\underline{Z}, \bar{Z}]$, so consistency dictates that the admissible action spaces depend on z^g. However, the interval I can be assumed sufficiently large such as not to constrain the players' equilibrium choices. Finally, the restriction of the players' strategy spaces to comprise only mappings from the aggregate state z^g into actions qualifies the model as a discounted Markov-stationary game with uncountable state and action spaces.

The data of the economy introduced so far are sufficient to characterize a competitive equilibrium for a sequence of arbitrary policy choices. What is lacking to pin down these policy choices are (i) the preferences of the two policy making authorites as represented by their objective functions, and (ii) an appropriate definition of a game-theoretic equilibrium. We now turn to the former issue. For that purpose, let $U(z, z^g; \varphi)$ be the lifetime utility enjoyed by a household with individual state $z = \frac{B(1+R)}{M}$ when the aggregate state is z^g and the policy rule employed by the two authorities is φ. We assume that both the monetary and the fiscal authority are benevolent in the sense that their payoffs derive from the lifetime utility enjoyed by the representative consumer. Specifically, for both authorities, the objective function is:

$$\sum_{t=0}^{\infty} \beta^t \left\{ log(c_t) - \alpha n_t \right\}$$

Let $V(z^g; \varphi)$ denote the fiscal value function induced by a given aggregate state z^g and policy rule φ; similarly, the monetary value function is given by $W(z^g; \varphi)$. The

[7]Note that in the setup considered here, where the players in each stage game $\mathcal{G}$ move only once and take the strategies of both authorities' future incarnations as given, strategies and actions coincide.

payoff functions $\hat{V}(z_t^g; \pi, \varphi)$ and $\hat{W}(z_t^g; \pi, \varphi)$, which are relevant in the stage game $\mathcal{G}(z_t^g; \varphi)$ indexed by the aggregate state z^g and a continuation play φ, derive from these value functions and will be defined in Section 1.3.2.

Finally, our concept to pin down policy choices is Markov-perfect equilibrium (MPE). Accordingly, the main goal is to identify a policy rule $\varphi(z^g)$ which is time consistent.[8] This means that the authorities must not have an incentive to deviate from this rule when they noncooperatively choose their policy instruments, taking their future incarnations' continuation play as given. Finding such a policy rule involves three steps:[9]

1. Define the economic equilibrium for arbitrary policy rules φ. This allows to determine the representative household's welfare level as well as the authorities' value functions for arbitrary policy rules φ.

2. Define the optimal equilibrium policy π in the current period when future policies are determined by some arbitrary policy rule φ. Since the optimal current policy depends on the current state, this step determines the optimal current policy rule $\pi(\varphi)$, given a future rule φ.

3. Define the conditions under which the authorities will not deviate from the rule assumed for the future, i.e. impose time consistency on the policy rule. Time consistency will obtain if the policy rule assumed for the future is equal to the rule that is optimal in the current period (policy fixed point): $\varphi = \pi(\varphi)$.

With this structure, the policy equilibrium can be represented recursively.

1.3.1 Equilibrium for arbitrary policy rule

We define the household's problem recursively, whereby it is important to note that the problem is conditional on the policy functions for the fiscal and the monetary authority; this influence is summarized by the argument φ of the value function. We have:

$$U(z, z^g; \varphi) = max_{c,n,B',M'} \left\{ [log(c) - \alpha n] + \beta U(z', z'^g; \varphi) \right\}, \tag{1.11}$$

[8]That is, we are looking for time consistent Markov policies rather than dynamically inconsistent Ramsey policies. In the language of Ortigueira (2006), we are considering quasi time consistent policies since we assume that the two authorities move first and determine their policies before the households decide about their individual variables. This modelling choice can have important implications for the interpretation of what commitment is as well as for the quantitative equilibrium outcomes. Moreover, it implicitly stipulates that the equilibrium targeted by the authorities is actually implemented. This implies that the households' beliefs must presume that, within a period, the authorities can commit to their choices of τ^c and M'^g, even if this is physically not feasible.

[9]The procedure has been developed by Klein, Quadrini and Ríos-Rull (2005) who apply it to analyze a model of international tax competition.

where the maximization is subject to the private budget constraint (1.3), the CIA constraint (1.5), the no-Ponzi condition (1.4) and conditional on policies:

$$\begin{aligned} \tau^c &= \tau^c(z^g;\varphi) \\ M'^g &= M'^g(z^g;\varphi) \end{aligned}$$

and a perceived law of motion for the endogenous aggregate state:

$$\bar{z}'^g = G^e(z^g;\varphi)$$

The solution to the private household problem are the individual decision rules $c(z,z^g;\varphi)$, $n(z,z^g;\varphi)$, $B'(z,z^g;\varphi)$ and $M'(z,z^g;\varphi)$. These decision rules are characterized by the following first order conditions:

$$\begin{aligned} \frac{1}{\alpha c_t} &= (1+R_t)(1+\tau_t^c) \\ (1+R_{t+1}) &= \frac{1}{\beta}\frac{P_{t+1}}{P_t} \end{aligned}$$

We can now formulate our definition of a competitive equilibrium in a recursive manner.

Definition 1.2 *A recursive competitive equilibrium for given policies φ consists of a household value function $U(z,z^g;\varphi)$, individual decision rules $\{c(z,z^g;\varphi), n(z,z^g;\varphi), B'(z,z^g;\varphi), M'(z,z^g;\varphi)\}$ and an aggregate function $G^e(z^g;\varphi)$ such that:*

1. *households optimize, i.e. given the states (z,z^g), policies φ and a perceived law of motion $G^e(z^g;\varphi)$, the value function $U(z,z^g;\varphi)$ and the decision rules $\{c(\cdot), n(\cdot), B'(\cdot), M'(\cdot)\}$ solve the household problem;*

2. *the perceived law of motion is the actual law of motion, i.e. households are representative and form rational expectations:*

$$z' = z'^g = G^e(z^g;\varphi)$$

3. *the pursued policies are feasible, i.e. the consolidated budget constraint of the government sector is satisfied in every period:*

$$M'^g + B'^g + P\tau^c c = M^g + B^g(1+R) + Pg.$$

Thus, using the optimal household decisions in response to a policy rule φ, we can solve for the houshold value function $U(z,z^g;\varphi)$. If the authorities' policy choices are governed by the policy rule φ, their value functions can be described as follows.[10] For the fiscal authority, conditional on the policy rule φ, we have:

$$V(z^g;\varphi) = \{[log(c(z^g;\varphi)) - \alpha(c(z^g;\varphi)+g)] + \beta V(z'^g;\varphi)\}$$
$$\text{s.t.} \qquad \frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'^g}{(1+\mu(z'^g;\varphi))} - c(z^g;\varphi) - \frac{\beta}{\alpha}\frac{z^g}{(1+\mu(z^g;\varphi))} = 0,$$

where $\mu \equiv \frac{M'^g}{M^g} - 1$ is the rate of money expansion. Similarly, for the monetary authority, we have:

$$W(z^g;\varphi) = \{[log(c(z^g;\varphi)) - \alpha(c(z^g;\varphi)+g)] + \beta W(b'^g;\varphi)\}$$
$$\text{s.t.} \qquad \frac{\beta}{\alpha} - g + \beta z'^g c(z'^g;\varphi)(1+\tau^c(z'^g;\varphi)) - c(z^g;\varphi) - z^g c(z^g;\varphi)(1+\tau^c(z^g;\varphi)) = 0$$

1.3.2 Optimal current policy rule for given future policy rule

We look for a MPE where both authorities know the other one's policy function and take it as given. Clearly, the optimal control laws depend on each other, but in the MPE with simultaneous moves each authority ignores the influence that its choice exerts on the other authority's current choice. Nevertheless, due to the consolidated government budget constraint there is two-sided interaction. Specifically, the government budget constraint determines the law of motion for the endogenous aggregate state variable z^g. For a given future policy rule, which conditions on the aggregate state, this means the following: Each authority, taking the respective other authority's current policy choice as well as the future continuation play as governed by φ as given, faces a situation where its own current policy choice affects both its current payoff and its value from the next period onwards.

Let $\pi = (\pi_f, \pi_m)$ denote the current policy rule, and let $\varphi = (\varphi_f, \varphi_m)$ denote the future policy rule. Taking the policies as given, the household problem then is as follows (all variables which are affected by the current policies π are denoted with a hat; note that the relevant next period value function for given policies φ is the one derived in the previous section):

$$\hat{U}(z, z^g; \pi, \varphi) = max_{c,n,B',M'}\{[log(c) - \alpha n] + \beta U(z', z'^g; \varphi)\}, \qquad (1.12)$$

where the maximization is subject to the private budget constraint (1.3), the CIA constraint (1.5), the no-Ponzi condition(1.4) and conditional on policies:

$$\begin{aligned} \tau^c &= \hat{\tau}^c(z^g;\pi,\varphi) \\ M'^g &= \hat{M}'^g(z^g;\pi,\varphi) \end{aligned}$$

[10] The equations presented in the following are derived from a primal approach to the authorities' problems; the respective problems are conditional on the other authority's policy rule as well as on the mapping governing the formation of private expectations. The primal approach reformulation of the relevant decision problems is done in Appendix A.2.

and and a perceived law of motion for the endogenous aggregate state:

$$\bar{z}'^g \;=\; \hat{G}^e(z^g;\pi,\varphi)$$

With the appropriate notational changes, a recursive competitive equilibrium for arbitrary current policy actions π followed by future policy rule φ is then defined like above recursive competitive equilibrium for given policies φ.

Faced with a continuation policy rule φ, the authorities' problem consists of optimally determining their contemporaneous policies π. For the fiscal authority, we have the following:

$$\hat{V}(z^g;\pi,\varphi) = max_{\pi_f}\{[log(c(z^g;\pi)) - \alpha(c(z^g;\pi)+g)] + \beta V(z'^g;\varphi)\},$$

where the maximization is subject to the fiscal implementability constraint derived from the periodically consolidated government budget constraint (with $\mu(z^g;\pi_m)$ determined by the monetary authority's contemporaneous policy choice as prescribed by the monetary rule π_m):

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'^g}{(1+\mu(z'^g;\varphi))} - c(z^g;\pi) - \frac{\beta}{\alpha}\frac{z^g}{(1+\mu(z^g;\pi_m))} = 0 \tag{1.13}$$

For the monetary authority, we have:

$$\hat{W}(b^g;\pi,\varphi) = max_{\pi_m}\{[log(c(z^g;\pi)) - \alpha(c(z^g;\pi)+g)] + \beta W(z'^g;\varphi)\},$$

where the maximization is subject to the monetary implementability constraint derived from the periodically consolidated government budget constraint (with $\tau^c(z^g;\pi_f)$ determined by the fiscal authority's contemporaneous policy choice as prescribed by the fiscal rule π_f):

$$\frac{\beta}{\alpha} - g + \beta z'^g c(z'^g;\varphi)(1+\tau^c(z'^g;\varphi)) - c(z^g;\pi) - z^g c(z^g;\pi)(1+\tau^c(z^g;\pi_f)) = 0 \tag{1.14}$$

Note that the two authorities maximize directly over their current policies (π_f and π_m, respectively), taking their respective opponent's current action as given and, via φ, facing given functions governing the continuation play by succeeding government authorities. The current authorities make their policy choices simultaneously: Conditional on a continuation play φ, the fiscal authority chooses π_f to maximize $\hat{V}(z^g;\pi,\varphi)$, given π_m, and the monetary authority chooses π_m to maximize $\hat{W}(z^g;\pi,\varphi)$, given π_f. This leads to the following definition:

Definition 1.3 *Given the functions $\varphi = (\varphi_f,\varphi_m)$, a Nash equilibrium of the stage game is a pair of functions $\{\pi_i^*(z^g;\varphi)\}_{i=f,m}$ such that (i) $\pi_f^*(z^g;\varphi)$ maximizes $\hat{V}(z^g;\pi,\varphi)$, given $\pi_m^*(z^g;\varphi)$, and (ii) $\pi_m^*(z^g;\varphi)$ maximizes $\hat{W}(z^g;\pi,\varphi)$, given $\pi_f^*(z^g;\varphi)$.*

By construction, the Nash equilibrium will consist of feasible policies. However, out of equilibrium the payoffs may not be well-defined. For example, this will be the case for policy choices which are jointly inconsistent with a competitive equilibrium. Then, the question is what will happen out of equilibrium. Noting that the described environment and the rules according to which the two authorities interact in this environment fall short of the formal description of a proper game, we will nevertheless proceed to analyze the MPE outcomes.[11]

1.3.3 Policy fixed point

Now, we can define the equilibrium time consistent policies:

Definition 1.4 *The policy rules* $\varphi = (\varphi_f, \varphi_m)$ *define time consistent policies if they are the Nash solution of the stage game when the two authorities expect* φ *to determine future policies. Formally:* $\varphi_i(z^g) = \pi_i(z^g; \varphi)$*,* $i = f, m$*.*

Finally, a MPE of the policy game described above is a profile of Markov strategies for the two authorities that yields a Nash equilibrium in every proper subgame.[12]

1.4 Solution strategy

The implementation of the program defining the solution of the problem described above makes use of a primal approach representation, where the authorities maximize directly over their preferred allocation variables c and z'^g rather than over their true policy instruments.[13] Finding the equilibrium time consistent policy rule involves the three steps described in the previous section, the details of which are laid out in Appendices A.4 to A.6. While formulating the policy game directly in the primal space comes at the additional cost that one has to take care that the authorities' preferred allocations are mutually consistent, a primal approach has the advantage that it is much easier to recover the policies - if they are uniquely determined - from the allocation compared to the problem when the inference goes in the reverse direction: To recover the policies from the allocation requires nothing but the solution of a set of equations for the unknown policies. Conversely, to infer the

[11] The problem is that the outcome and the associated payoffs are not well-defined in situations where a consistency condition, defined by equation (1.15) below, is not satisfied for some positive consumption level. In such situations, the authorities' policy choices τ^c and M' are incompatible with a competitive equilibrium. In a related context, but with only one authority, a possible solution to this lack of formal structure has been suggested by Bassetto (2002, 2005) who proposes the introduction of an explicit market microstructure and the adoption of a modified notion of government policy within a period as contingent strategy rather than as uncontingent plan.

[12] For formal definitions of MPE in general games, see e.g. Fudenberg and Tirole (1993).

[13] Compare Chari and Kehoe (1998) for a general exposition of the methodology.

allocation from the policies requires to solve a nonlinear optimization problem. The latter complication stems from the fact that one has to solve the private household's optimization problem for the given policies to obtain the allocation, while a primal approach, in deriving the respective implementability constraints, takes care of this problem by substituting the private first order conditions into the government budget constraint.

The qualification for the applicability of a primal approach to a dynamic game is the question of whether, for a given continuation policy φ, there is a one-to-one mapping between the set of Nash equilibria in policies and the set of Nash equilibria in allocations. It turns out that indeed this mapping is one-to-one. The reason for this result is that, in each period, no matter whether the authorities' optimization problems are cast in terms of their true policy instruments, i.e. τ^c and M'^g, or directly in terms of the allocation variables, i.e. c and z'^g, the equilibrium choices must not only give rise to a competitive equilibrium, but simultaneously constitute a Nash equilibrium in the stage game interaction between the two authorities. The second requirement is taken care of in both strategic setups by making the constraints faced by the two authorities contingent on the (belief about) the *policy instrument* employed by the respective opponent. Then, it is straightforward to see that the two representations of the problem are strategically equivalent. Therefore, the solution of the dynamic policy game is immune with respect to changes in the choice variables.

1.5 Markov-perfect equilibrium outcomes

Starting from the primal approach representation of the dynamic game developed in the Appendix and assuming differentiable Markov strategies, it is useful to present the two authorities' first order conditions with respect to their choice variables c and z'^g for a given continuation policy φ (step 2 above). These first order conditions together with a consistency condition, which requires that the implementability constraints faced by the two authorities are mutually compatible, are necessary conditions characterizing a MPE under rational expectations.[14] Formally, an equilibrium with rational expectations is characterized as a fixed point between expectations and realizations; that is, in the equilibrium of the deterministic model, we require that private expectations and realizations as governed by the authorities' first order conditions conditional on these given expectations must coincide. Moreover, as an implication of a Nash equilibrium prevailing in every stage game, it must be the case that the two authorities' conjectures about their respective opponent's contempora-

[14]The relevant equations are derived in Appendix A.2 and Appendix A.5, respectively. In what follows, we drop the superscript g since in equilibrium the representative household's individual state z and the aggregate state z^g must coincide.

neous play as well as about the future continuation play are correct. Specifically, in any MPE, the following consistency condition, which guarantees that the two authorities' dynamic programs and their respective solutions are mutually consistent and decentralizable as a competitive equilibrium, must hold:

$$c(1+\tau^c(z;\varphi))(1+\mu(z;\varphi)) = \frac{\beta}{\alpha} \tag{1.15}$$

Then, the fiscal authority's first order conditions with respect to c and z' are:

$$\frac{1}{c} - \alpha \quad = \quad \lambda_f \tag{1.16}$$

$$V'(z';\varphi) \quad = \quad -\lambda_f \frac{\beta}{\alpha}(1+\mu(z';\varphi))^{-1}\left[1-\varepsilon_\mu(z';\varphi)\right], \tag{1.17}$$

where λ_f is the Lagrange multiplier on the implementability constraint (1.13) faced by the fiscal authority and $\varepsilon_\mu(z;\varphi) \equiv \frac{\partial(1+\mu(z;\varphi))/\partial z}{(1+\mu(z;\varphi))/z}$ is defined to be the elasticity of (gross) monetary expansions $(1+\mu(z;\varphi))$ in response to changes in the aggregate state z. Importantly, we have $1 > \varepsilon_\mu(z;\varphi) \geq 0$ because the monetary authority's incentives to monetize outstanding government liabilities via the inflation tax are a non-decreasing function of the stock of inherited debt burden z. Combining above equations and making use of the consistency condition (1.15) to substitute for $\frac{\beta}{\alpha}(1+\mu(z';\varphi))^{-1}$ gives:

$$\frac{1}{c} - \alpha = -\frac{V'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))}\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1} \tag{1.18}$$

This condition requires that the marginal benefit from current consumption be equal to the *amplified* marginal cost of future government liabilities. The amplification, reflected via the term $\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1} \geq 1$, results from the fact that the increased public liabilities, which must be accumulated to order to facilitate higher current consumption, make future consumption more costly not only because higher debt crowds out consumption, but also because of its expectational effects: A higher debt burden (weakly) increases the future monetary authority's incentives to resort to the inflation tax which is anticipated by the public and leads to a distortion in nominal interest rates; this, in turn, constitutes an opportunity cost of consumption due to the CIA constraint. The implications of this distortion become more apparent if an envelope condition and the optimality condition (1.16) are used to substitute for the value function term in (1.18) to arrive at:

$$\frac{1}{c} - \alpha = \left(\frac{1}{c(z';\varphi)} - \alpha\right)\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1} \tag{1.19}$$

Equation (1.19) reveals that the current fiscal authority, although it is not per se subject to a time consistency problem, is not guaranteed to act like a Ramsey policy maker, but, in trying to smooth distortions over time, will also take into account future incentive problems. The latter depend on the continuation play φ and are reflected by the term $[1 - \varepsilon_\mu(z';\varphi)]^{-1}$ which, taking into account future commitment problems, scales up the marginal benefit of future consumption.

The situation for the monetary authority is slightly different, as can be seen from its relevant first order conditions:[15]

$$\frac{1}{c} - \alpha \;=\; \lambda_m[1 + z(1 + \tau^c(z;\varphi))] \tag{1.20}$$

$$W'(z';\varphi) \;=\; -\lambda_m c(z';\varphi)(1 + \tau^c(z';\varphi))\,[1 - \varepsilon_\mu(z';\varphi)]\,, \tag{1.21}$$

where λ_m is the Lagrange multiplier on the implementability constraint (1.14) faced by the monetary authority. Combining above equations gives:

$$\frac{\frac{1}{c} - \alpha}{[1 + z(1 + \tau^c(z;\varphi))]} = -\frac{W'(z';\varphi)}{c(z';\varphi)(1 + \tau^c(z';\varphi))}\,[1 - \varepsilon_\mu(z';\varphi)]^{-1} \tag{1.22}$$

In contrast to the fiscal optimality condition (1.18), optimality from the monetary authority's perspective dictates not only that the marginal costs from increased future liabilities need to be scaled up by the term $[1 - \varepsilon_\mu(z';\varphi)]^{-1}$, but also that the current marginal benefit from consumption is *reduced*. While the former aspect reflects the same commitment problem of future policy makers that was also relevant for the current fiscal authority, the latter aspect is specific to monetary policy. The reason is that, at the monetary margin for a given fiscal policy, increasing current consumption, by virtue of the (binding) CIA constraint, necessitates a lower price level which has the effect that the real value of the outstanding liabilities is increased; this additional cost of higher consumption is captured via the term $[1+z(1+\tau^c(z;\varphi))] \geq 1$ in the denominator on the LHS. Another way to understand this discounting of the marginal benefit from current consumption is to realize that higher current consumption requires that, at the margin, the monetary authority refrains from using the inflation tax which would operate as a lump-sum levy on the outstanding liabilities; rather, the intertemporal budget constraint has to be satisfied via future distortions. It is this trade-off between the lump-sum aspect of the inflation tax against the necessary distortions induced via future policies which is the source of the monetary time consistency problem. Similar to the fiscal problem, an envelope condition and the optimality condition (1.20) can be used to gain further insights from a simple intertemporal condition for the current monetary

[15] With the difference that the tax policy is fully specified here, these are essentially the first order conditions derived by Díaz-Giménez et al. (2006) in their model of optimal monetary policy. However, the decentralization of authority over policies will be shown to fundametally change their dependence on the continuation play φ.

policy maker:

$$\frac{\frac{1}{c}-\alpha}{[1+z(1+\tau^c(z;\varphi))]}=\frac{\frac{1}{c(z';\varphi)}-\alpha}{[1+z'(1+\tau^c(z';\varphi))]}\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1}, \tag{1.23}$$

which highlights that consumption smoothing proceeds under two distortions: First, the distortion due to the lack of commitment of future policy makers as captured by the term $[1-\varepsilon_\mu(z';\varphi)]^{-1}$. And second, the current incentive problem reflecting the possibility to reduce the real value of the inherited nominal liabilities z; as we will show below, this latter incentive probelm is crucially shaped by the current fiscal authority's behavior.

Having established the necessary conditions that characterize a differentiable MPE, its existence should be verified. Existence results for MPE in games of the class considered here are generally hard to obtain. In our specific context, we can establish the following:

Proposition 1.1 *The infinite-horizon game has a (differentiable) Markov-perfect equilibrium in stationary strategies.*

The proof for this proposition is adapted from Amir (1996) and can be found in Appendix A.3. Basically, it proceeds by showing that a player's best response to a monotone and Lipschitz-continuous time-invariant strategy employed by the respective other player is again monotone and Lipschitz-continuous. Then, since the space of Lipschitz-continuous functions is a compact and convex subset of the Banach space of bounded continuous functions and since the best response mapping is continuous, Schauder's fixed point theorem can be invoked to establish the existence of a MPE in stationary strategies. It turns out that there are two classes of differentiable equilibria whose outcomes satisfy the necessary conditions (1.15) to (1.17) and (1.20), (1.21) established above. Apart from these differentiable MPE, additional non-differentiable MPE may exist;[16] in what follows, our focus will be entirely on differentiable MPE. It is convenient to classify the differentiable MPE corresponding to the allocations they implement. In particular, we will see that the

[16]Multiplicity of equilibria has been found to be an issue in environments whose key elements are discontinuities in decision rules and conflicting objective functions of the players at different points in time, e.g. in (single-agency) optimal policy problems without commitment or in problems with quasi-geometric discounting. For an analysis of Markov strategies characterizing consumption-savings decisions with quasi-geometric discounting, see e.g. Krusell and Smith (2003). However, the nature of multiplicity in these single-agency problems is fundamentally different from the one that arises in our two agency context as an instance of coordination failure among the interacing authorities. In papers exploring single-agency MPE of dynamic games in macroeconomic settings, e.g. Klein and Ríos-Rull (2003), Klein, Krusell and Ríos-Rull (2003) or Krusell, Kuruscu and Smith (2002), the focus is generally on differentiable policy functions.

respective equilibrium outcomes reproduce *either* the allocation implemented under a single policy maker who controls the complete set of policy instruments (quasi-single agency) *or* the allocation in an economy with indexed debt (quasi-indexation).

1.5.1 The quasi-single agency MPE

It is immediate that the MPE outcome identified in Díaz-Giménez et al. (2006) for the single-agency economy also constitutes a MPE outcome with interacting authorities. The reason for this result is that an optimal policy outcome under single-agency must have been decentralized by choices for the different policy instruments which have the property of being mutual best responses. If this was not the case, there would be an incentive to revise the policies which would contradict an equilibrium. To further verify the claim in the context of the specific policy game considered, it is sufficient to start from the assumption that the policy rule φ governing the continuation play is precisely the equilibrium policy these authors have identified in their single-agency environment. This continuation policy involves a gradual decumulation of debt by means of the inflation tax; the consequence is that $\varepsilon_\mu(z';\varphi) > 0$. We denote an economy with $\varepsilon_\mu(z';\varphi) > 0$ as subject to an *inflation bias*. Accordingly, an inflation bias characterizes a situation where outstanding debt, because it is the source of dynamically inconsistent incentives for the monetary policy maker, causes extra liability costs beyond those due to the need to balance the intertemporal government budget via distortionary taxation. The authorities' optimal response to such a constellation is to decumulate the stock of debt today because in doing so future incentive constraints can be relaxed. At the beginning of any given period, private expectations are predetermined, so that the inflation tax, apart from constraining consumption via the CIA constraint, will operate in a lump-sum fashion on the stock of debt, an inelastic tax base. Therefore, the assumed future equilibrium policy will optimally be reproduced in the current period, and a MPE with interacting authorities is established. The allocation associated with this MPE solves equations (1.15) to (1.17) and (1.20), (1.21), whereby $\varepsilon_\mu(z';\varphi)$ is strictly positive as long as there are positive amounts of outstanding debt because the public rationally anticipates the inflation bias induced by sequential optimization and nominal debt; the result is an upward distortion in nominal interest rates which crowds out private consumption. We summarize our results in:

Proposition 1.2 *In the policy game with interacting authorities, there exists a (differentiable) Markov-perfect equilibrium which reproduces the Markov-perfect equilibrium allocation implemented by a single, sequentially optimizing authority controlling the same policy instruments. In particular, nominal debt bears liability costs and gives rise to an inflation bias as long as there are positive amounts of nominal debt.*

In order to illustrate the dynamics implied by the this MPE, we resort to a numerical example. The algorithm used to compute the MPE is detailed in Appendix A.7. To carry out the numerical exercise, we choose the following parameterization, which, for the purpose of comparison, draws largely on Díaz-Giménez et al. (2006): $\alpha = 0.45$, $\beta = 0.98$, $b_0 = \frac{z_0}{(1+R_0)} = 1.28$, $g = 0.5$. The dotted trajectories in Figures 1.1 and 1.2 give the time paths of the real stock of debt $b \equiv \frac{z}{(1+R)}$ and consumption associated with the quasi-single agency MPE; this MPE under interaction coincides with the equilibrium reported in Díaz-Giménez et al. (2006) for the case of a single policy maker who cannot commit. As expected, the stock of debt is progressively depleted until it disappears.[17] This pattern is inversely reflected in the path of consumption which increases until it reaches its stationary long-run level corresponding to the long-run level of zero debt.

1.5.2 The quasi-indexation MPE

We now demonstrate that the separation of authority over macroeconomic policies facilitates the existence of another class of MPE. Such MPE are constructed based on the conjecture that the continuation policy φ will be such that (i) the sequence of future monetary authorities will remain passive in the sense of not being marginally responsive to the stock of real liabilities, i.e. $\varepsilon_\mu(z';\varphi) = 0$ for all z' and that (ii) the sequence of future fiscal authorities will be such as to keep the aggregate state z constant over time. Since the assumed continuation play implies that future monetary policy makers will refrain from monetary expansions, we have $\varepsilon_\mu(z';\varphi) = 0$. How will the pair of current best response policies to such a continuation rule look like? Given $\varepsilon_\mu(z';\varphi) = 0$, outstanding liabilities do not have adverse expectational effects and the optimal monetary policy in the current period will be to stay passive, provided the current fiscal policy generates sufficient revenue via the consumption tax such as to keep the stock of real liabilities z constant. The reason is that, taking as given a fiscal policy that keeps the stock of real liabilities z constant, it is too costly to further drive down this stock of debt by an additional monetary expansion,[18] if the motive of relaxing future incentive constraints is not present. But precisely this is the case if φ is such that $\varepsilon_\mu(z';\varphi) = 0$. On the other hand, the current fiscal authority will find it optimal to balance the budget via the consumption tax when facing a sequence of current and subsequent monetary policy makers who refrain from the inflation tax. This reasoning verifies the existence of a MPE characterized

[17] As shown by Martin (2006), this particular result follows from the unitary intertemporal elasticity of substitution implied by log-utility in consumption, which, for any positive level of debt, makes the incentive to inflate prices dominate over the incentive to defer distortions into the future by maintaining a higher stock of debt.

[18] Recall that unexpected monetary expansions constrain consumption by virtue of the CIA constraint.

by a policy rule that gives rise to $\varepsilon_\mu(z;\varphi) = 0$.

The outcomes associated with this MPE are characterized as follows: From (1.19) and (1.23), it follows that both the aggregate state z and the level of consumption c must be constant over time. Thus, abstracting from potential fluctuations in government spending, the environment is completely stationary. Inspection of either implementability constraint, evaluated at a stationary allocation, then reveals that the flat path for consumption is given by:[19]

$$c = \frac{\beta}{\alpha}\left[1 - (1-\beta)z\right] - g \tag{1.24}$$

With $\varepsilon_\mu(z;\varphi) = 0$, but irrespective of the constant rate of money growth $(1+\mu(z))$, the stationary allocation implemented by this equilibrium with decentralized authority mimics the real allocation resulting from a single-agency problem with indexed debt. In the latter scenario, by construction, there is no monetary time inconsistency problem; this leads to the following proposition:

Proposition 1.3 *In the policy game with interacting authorities, there exists a (differentiable) Markov-perfect equilibrium which reproduces the Markov-perfect equilibrium allocation under indexed debt, provided the initial level of liabilities z_0 is such that $c(z_0) > 0$ in (1.24). There are no transitory dynamics, and there is no inflation bias.*

The allocation associated with the quasi-indexation equilibrium under interaction is graphically depicted by the solid trajectories in Figures 1.1 and 1.2 which were constructed using the same parameter values as for the previous example. The numerical results confirm the theoretical argument that the implemented allocation is stationary. Comparison with the allocation implemented by the quasi-single agency MPE reveals that the quasi-indexation MPE involves a superior balancing of distortions over time: While the long-run level of consumption is lower, the initial levels are not depressed downwards, and the result is a higher lifetime utility enjoyed by the representative household. This last argument is summarized graphically in Figure 1.3 which compares the equilibrium levels of welfare under the two regimes.

1.5.3 The role of interaction

It is interesting to investigate from a game-theoretic perspective why the decentralization of authority over policy decisions allows for the emergence of a new MPE

[19]In deriving (1.24), we have exploited the rational expectations consistency condition which links the initial interest rate $(1+R_0)$ to the initial rate of money expansion $(1+\mu_0)$. The implication is that the ratio $\frac{z_0}{(1+\mu_0)} = \frac{B_0}{M_0}\frac{(1+R_0)}{(1+\mu_0)}$ does not depend on the initial rate of money growth. Consequently, (1.24) holds for any stationary allocation, irrespective of the stationary rate of money growth $(1+\mu)$.

which was not sustainable in a single-agency economy where the policy maker controls both policy instruments, τ^c and M'. Specifically, it may not be immediately clear why the quasi-indexation MPE with interacting authorities is not an equilibrium with a single policy maker. The point is that a single decision maker should in principle be able to replicate anything that could be implemented as an equilibrium with interaction among separate government authorities. This issue is of particular relevance because the quasi-indexation equilibrium which becomes available under interaction dominates the single-agency equilibrium both in welfare terms and in a Pareto sense from the two authorities' perspective.

So why is the stationary equilibrium under interaction not an equilibrium with a single decision maker? The answer to this question lies in the underlying time inconsistency problem of the monetary authority and the properties of the respective policy instruments. With a monolithic policy maker, it is the case that, once private expectations are fixed, whatever is done via the consumption tax τ^c can be done more efficiently via the inflation tax induced by money injections M'. The reason is that, while both policy instruments operate on the same distortionary margin, the inflation tax has the additional benefit of relaxing future implementability constraints by deflating the inelastically supplied real stock of debt. Thus, the single policy authority has always an incentive to substitute M' for τ^c and is thus subject to a time inconsistency problem which makes a non-inflationary equilibrium unsustainable.

Conversely, with interacting authorities, the quasi-indexation equilibrium is sustainable due to the asymmetry of the dynamic constraints faced by the two authorities. While the monetary authority is still subject to a time inconsistency problem, the fiscal authority is not subject to such a problem because, even when private expectations are fixed, its policy instrument does not allow for non-distortionary revenue generation. Indeed, with decentralized decision power, each authority makes its current policy choice not only for given private expectations, but - as an implication of the Nash equilibrium prevailing in any stage game - also for a *given current policy choice by the respective other authority.* That is, unlike in standard optimal policy models, decentralized decision making does not allow to substitute one policy instrument for another because the respective other authority's policy rule is a given constraint rather than a free choice variable. In other words, the reason why a time consistent policy rule φ implying $\varepsilon_\mu(z;\varphi) = 0$ can be sustained is an instance of *coordination failure* among the two interacting authorities. The consequence is that there is scope for a favorable coordination of private expectations under decentralized decision power over policies: A fiscal policy which keeps the level of real debt constant without the need to recur to the inflation tax makes zero-inflation expectations rational.[20] But given such expectations, the extra liability costs of

[20]As indicated by (1.8), what ultimately matters is the composite distortion $(1 + R)(1 + \tau^c)$

nominal debt vanish, and consequently the rationale for an erosion of the stock of outstanding debt via surprise inflation disappears. The point is that the monetary authority is not willing to subject the economy to additional distortions on top of those already caused by the fiscal authority in order to drive down the stock of real debt.[21]

Crucial for this conclusion is that not only the current fiscal authority's play is taken as given (i.e. $\tau^c(z)$ is a given number), but that the same is true also for the continuation play (i.e., in the proposed equilibrium, $\tau^c(z';\varphi)$ and $\mu(z';\varphi)$ are given nondecreasing functions). This makes the current monetary authority's problem different from the situation faced by a Ramsey planner who can simultaneously control future policies when deciding about the current allocation. Indeed, even when constrained by current taxes being fixed at a level that, absent a monetary expansion, would keep the aggregate state z constant, a Ramsey planner would decide to additionally use the inflation tax in order to relax the implementability constraint she will face in the subsequent period. In contrast, under sequential policy implementation, there is an additional feedback induced via the given future policy rule φ; this feedback makes the current monetary authority prefer to refrain from using the inflation tax.[22]

The stationarity of the allocation implemented via the quasi-indexation MPE suggests that the time inconsistency problem of optimal policy is not necessarily relevant with interacting authorities. To clarify this statement, two remarks are expedient: *First*, as a consequence of the fact that the two policy instruments considered are equivalent with respect to the margins that they distort, there may be multiple combinations of time invariant policy rules for τ^c and M' which decentralize the same allocation. This is true also for the quasi-single agency MPE, because what ultimately matters for the determination of a MPE is the value taken by the variable $\varepsilon_\mu(z';\varphi)$ and not the specific policy rule φ that decentralizes the allocation.

rather than the interest rate distortion in isolation. Indeed, there are also inflationary (in the sense of $(1+\mu(z)) > 1$) policy rules which implement the quasi-indexation allocation. The critical property of these policy rules is that monetary policy does not respond to marginal variations in the stock of real debt, i.e. $\varepsilon_\mu(z;\varphi) = 0$.

[21]This is a consequence of the intertemporal elasticity of substitution of one implied by log-utility. Specifically, the same forces that make a single policy maker implement policies that asymptotically drive the stock of real debt to zero (and not to negative or positive values) imply that the monetary authority, when faced with a budget balancing fiscal policy, does not want to inflate the economy any more. For a general specification of preferences, the described effect would emerge in a modified version, where the MPE outcome involves the authorities implementing a negative (positive) long-run level of real debt if the intertemporal elasticity of substitution is larger (smaller) than one.

[22]In this context, Díaz-Giménez et al. (2006) discuss an interesting constellation where the period t fiscal authority commits its policy (as a fixed number) one period in advance such that the feedback via the reaction of the period $t+1$ fiscal policy is absent; then, the quasi-indexation equilibrium collapses.

Hence, the key difference between the two classes of MPE is that, in the quasi-single agency MPE, inflation is always systematically related to the dynamic inconsistency in the policy problem which results in an inflation bias as long as there are positive amounts of outstanding public liabilities; in contrast, in the quasi-indexation MPE, the responsiveness of inflation to the stock of public liabilities z is always zero. *Second*, it has been established that the decentralization of authority over macroeconomic policies facilitates the existence of a MPE implementing a superior outcome because the interest rate distortions stemming from the dynamic inconsistency of optimal policies are absent. However, the inferior allocation implemented by the quasi-single agency MPE cannot be ruled out neither such that the economy is in a situation of multiple equilibria. Although the quasi-indexation MPE is welfare-superior and even Pareto-dominant from the two authorities' perspective, its selection is not automatically guaranteed because the authorities' period-by-period incentive to coordinate their policy choices - cutting back on τ^c and substituting via an increase in M' - makes the time consistency problem potentially reappear and thereby undermines the sustainability of the superior MPE.[23] Indeed, one might want to argue that communication between monetary and fiscal authorities renders the non-cooperative outcomes of Nash play implausible. Note however that, as long as formal contracts are unavailable, the set of self-enforcing plans (in the sense of correlated equilibria) under direct communication between the two authorities would still be given by randomizations among the Nash equilibria of the original non-cooperative game.[24] Hence, without further arguments, the quasi-indexation MPE cannot be dismissed.

1.6 Related literature and concluding remarks

The approach to optimal policy making presented in this paper relates to a well-established tradition in macroeconomic research. The dynamic inconsistency of optimal policy plans has been first identified by Kydland and Prescott (1977) and Calvo (1978); subsequently, Barro and Gordon (1983a,b) have applied this framework to a positive theory of monetary policy making. Starting with Lucas and Stokey (1983), also fiscal policy has been the topic of further research; important papers include Chari and Kehoe (1990), Klein and Ríos-Rull (2003) and Klein, Krusell and Ríos-Rull (2003). Further contributions to this branch of the literature then address the potential benefits which can be realized by a more complete set of disposable policy

[23]In this respect, since it gives rise to divergent objectives between the two authorities, the institution of a "conservative" central bank can be interpreted as a response to the fear that the policy making entities would have an incentive to coordinate their policy choices.

[24]Compare Myerson (1991), chapter 6.

instruments[25] or by delegation of authority over policy decisions. Specifically, in the context of Barro-Gordon type models where monetary policy faces the task of stabilizing output and inflation, the delegation to decision makers with biased incentives has received much attention; Rogoff's (1985b) weight-conservative central banker, inflation targets as proposed by Svensson (1997) and incentive contracts for central bankers as discussed by Walsh (1995) are prominent examples. However, a drawback with these analyses of optimal monetary policy is that fiscal policy is typically assumed to be absent or exogenous to the model; hence, policy interactions are neglected. Against this background, the present paper's innovation is to consider a setting with an inherent time consistency problem which gives rise to a dynamic policy game where monetary *and* fiscal policies are decided upon by two distinct sequentially operating authorities. Our main finding is that the properties of optimal policies implemented by a single decision making unit do not readily extend to a setting with simultaneous interaction between independent policy authorities. In particular, we have shown that nominal debt itself does not necessarily give rise to a time consistency problem as long as the fiscal authority is sufficiently flexible and benevolent.

So far, the interaction between monetary and fiscal policy in a dynamic framework with optimizing authorities seems to have been largely neglected in the literature. An exception is the recent work by Adam and Billi (2005) who investigate a sticky price economy with a structural inefficiency due to the market power of firms. In contrast to our problem where only monetary policy is subject to dynamically inconsistent incentives, their setup gives rise to a potential time consistency problem also for fiscal policy, which decides about the provision of public goods to be financed by lump-sum taxation. The authors analyze the dynamic economy under varying assumptions on the degree of the authorities' commitment. Their basic finding is that the monetary time inconsistency problem is more severe than the fiscal one. As a potential solution, they then propose a conservative central bank as an institutional arrangement that may mitigate the distortions associated with sequential policy making. Along the same lines, Dixit and Lambertini (2003) consider monetary-fiscal interactions with a conservative central bank and varying degrees of commitment of the two authorities. Their analysis shows how monetary commitment can be negated when fiscal policy is discretionary.

This finding is in stark contrast to our main result that it can be precisely the introduction of fiscal discretion which may solve a monetary time inconsistency problem. Specifically, we have demonstrated that the decentralization of decision authority over policy variables may be a powerful device to overcome the time inconsistency problem inherent in dynamic policy making. This result has been es-

[25]See e.g. Persson, Persson and Svensson (1987) who consider the implications of a richer maturity structure of government debt in overcoming the time consistency problem.

tablished within the framework of a non-cooperative dynamic game where the real value of the government sector's inherited liabilities takes the role of the relevant state variable. Thus, our contribution extends the described models of policy interaction by considering a truly dynamic game rather than a simple repeated economy. Our model features an endogenous state variable which has the consequence that the policy authorities' strategic calculus includes also their incentives to affect the environment in which their future incarnations will interact. Our starting point has been the non-strategic setup proposed by Díaz-Giménez et al. (2006). These authors do also consider the case of monetary-fiscal interactions, though under the simplifying assumption of fiscal commitment either within a period or over time. They argue that, if the fiscal authority has within-period commitment because it moves before monetary policy is implemented, then the results (described in the Introduction) derived for their benchmark case of a single policy maker remain valid; the reason would be that the monetary authority is still the residual policy maker and faces unchanged incentives as long as a non-negativity constraint on nominal interest rates is not binding. However, as shown in the present paper, this ineffectiveness result for fiscal policy under the assumption of sequential moves within a period fails to take into account that decentralized policy authority may allow to sustain a continuation policy which, in turn, induces a different equilibrium play in the current period. The second scenario considered by Díaz-Giménez et al. (2006) features an unconditional fiscal commitment extending over the entire path of future consumption taxes and generates results in line with the quasi-indexation MPE described here. Specifically, it is shown that a fiscal commitment to a tax policy balancing the budget periodically induces a passive monetary policy. However, an issue that is not explicitly addressed is the sequential optimality of fiscal policy in a truly strategic setup. This problem has been taken care of in our analysis which endogenizes fiscal policy choices.

Our analysis differs also from other papers which investigate non-cooperative policy games with respect to an important assumption: The established literature generally assumes that the objective functions of the relevant policy making authorities are not aligned, with the obvious consequence that there is a strategic conflict. An important contribution to that literature is Kehoe (1989) who shows that coordinating the choices of policy makers who strategically interact in order to increase their respective constituency's welfare can be counterproductive. The intuition for this result is that decentralized policy making gives rise to dynamic incentive constraints which allow for implicit commitment on behalf of the policy makers in environments where commitment with respect to future policy choices is otherwise impossible. Conversely, the present paper has started from a situation where decentralization proceeds under coincident objectives for the two benevolent policy makers. In this setup, what provides scope for superior results with interacting authorities is the fact that the fiscal authority is not subject to the time consistency problem facing the monetary authority. Indeed, if the subsequent fiscal authorities operate such as to guarantee a period-by-period balancing of the consolidated government budget, there is a twofold mechanism facilitating the coordination of the expectations of the third player in the economy, the continuum of private agents: Now, the monetary announcement not to let its choice for M' vary along with the future state becomes credible because (i) the fiscal reaction function acts as a constraint on the monetary rule, thus preventing the free substitution of one policy instrument (M') for another (τ^c), and (ii) the current fiscal play already imposes distortions which make resorting to the inflation tax prohibitively costly.

We have generated our results in the context of a simple dynamic general equilibrium economy with money and a government sector. Whereas most of the modeling choices made are standard, two assumptions deserve closer attention. The first one is the assumption of log-utility in consumption which has already been commented on at various occasions in the text. The second key assumption is to have the two interacting authorities move simultaneously in each period. Of course, the timing of events is crucial in any dynamic game. With respect to the interaction of monetary and fiscal policies, there seem to be conflicting views in the literature; compare e.g. the discussion in Dixit and Lambertini (2003). Although some authors, e.g. Beetsma and Bovenberg (1998), argue that fiscal policy is sluggish relative to monetary policy, we stick to a notion of simultaneous moves rather than formalizing the interaction in terms of a dynamic Stackelberg game, where, in each period, the fiscal authority moves first and the monetary authority follows. This timing structure is not uncontroversial and may be questioned with respect to its empirical relevance. We justify our assumption as follows: First, a simultaneous moves game is conceptually more straightforward to work with; moreover, as illustrated in the foregoing discussion, the insights generated on the basis of this timing protocol carry over to the Stackelberg case with fiscal leadership. Second, it is our view of monetary policy that considerations related to the interaction with fiscal variables play only a minor role for "day-to-day" operations, but are essential in shaping policy over the medium and long run when also fiscal policy has some flexibility. In any case, we provide a conceptual perspective on how the dynamic consistency of optimal policies changes once we introduce interaction between policy makers.

The most important policy implication emerging from the analysis is a caveat: Conventional wisdom holds that fiscal profligacy leading to soft budget constraints and the accumulation of public liabilities contributes to undermining a monetary commitment to price stability.[26] Consequently, it seems that institutional reforms

[26] Chapter two of this dissertation explores this issue with a particular emphasis on the role of monetary conservatism for the equilibrium dynamics of debt and the associated welfare implications.

introducing fiscal commitment or rules in the form of debt or deficit constraints are a good idea; in the context of the European Monetary Union, the Stability and Growth Pact codifies this notion. Conversely, our analysis suggests (admittedly, in a world of benevolent policy makers) that government debt is not necessarily a source of dynamically inconsistent incentives, and that fiscal rules may be, if anything, harmful; rather, the presence of a dynamically optimizing fiscal authority is needed to effectively constrain the conduct of monetary policy. It is in this sense that inflation ultimately is a fiscal phenomenon. However, the question of how the selection between the two different MPE proceeds remains an issue.

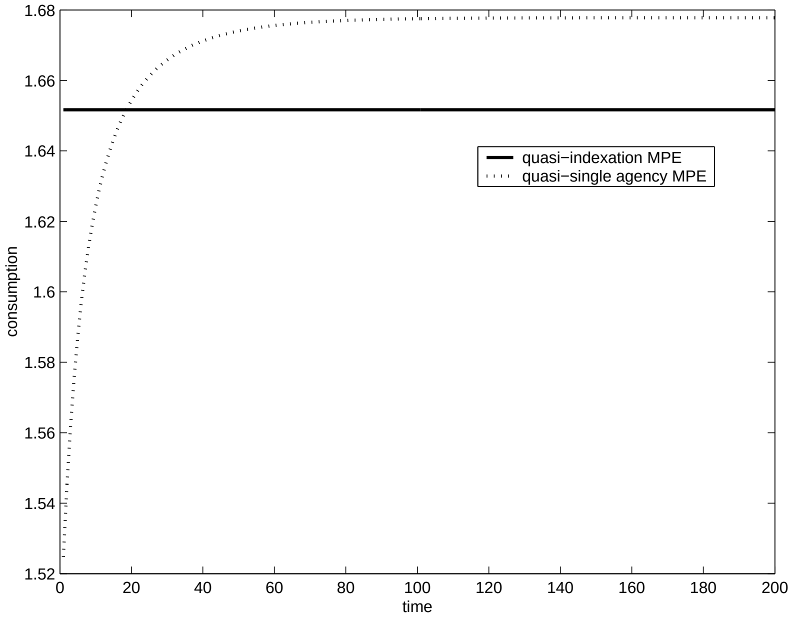

Figure 1.1: Paths of consumption in the quasi-indexation and quasi-single agency equilibrium

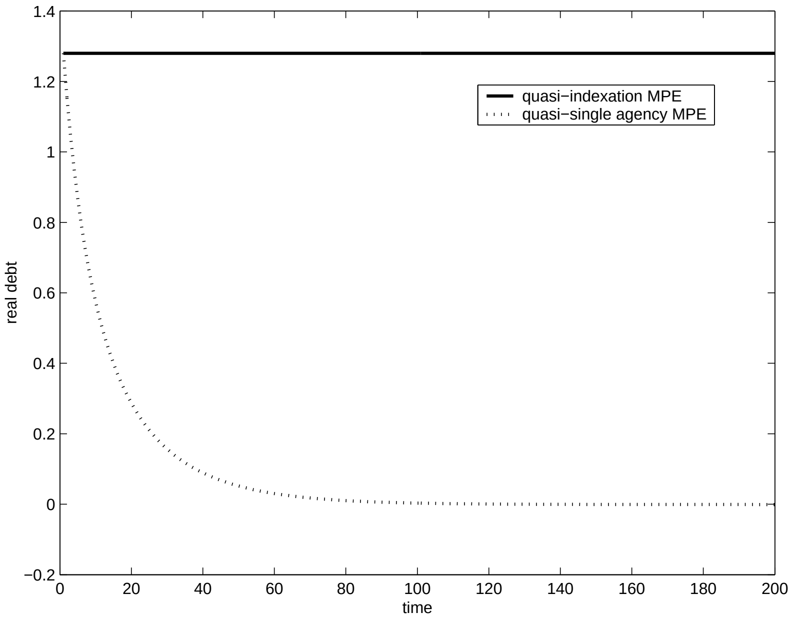

Figure 1.2: Paths of real debt in the quasi-indexation and quasi-single agency equilibrium

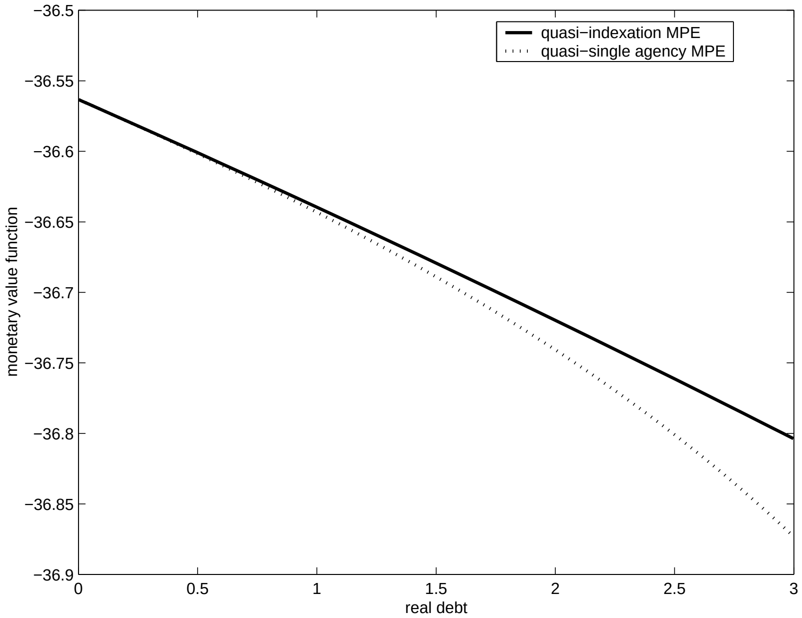

Figure 1.3: Welfare in the quasi-indexation and quasi-single agency equilibrium

Chapter 2

Dynamic Monetary-Fiscal Interactions and the Role of Monetary Conservatism

2.1 Introduction

During the last decades, normative proposals for the conduct of monetary policy have put increasing emphasis on inflation targets as a primary objective. Similarly, it is now an established consensus that central bank independence is an important institutional prerequisite for the success of monetary policy in achieving its goal of low and stable inflation. The view behind these two developments seems to be that a monetary authority can successfully implement a targeted path for inflation, once its statutes equip it with an appropriate mandate for price stability and the independence of monetary policy choices is warranted. However, it is not so clear whether the sufficiency of an independent and properly incentivized central bank for price stability survives in settings where the interaction between monetary and fiscal policies plays an important role.

Indeed, as argued among others by Woodford (2001), the case for the separation of decision authority over monetary and fiscal policies is based on two central presumptions: First, that fiscal policy is not an important determinant of inflation; and second, that the effects of monetary policy on the government budget are neglegible. A setting, where both of these tenets may be violated, is given by an economy with a significant amount of outstanding government debt in nominal terms. There, the second aspect is captured by the simple relationship that monetary policy, via its effect on the price level, affects the real value of outstanding public liabilities and thus the tightness of the intertemporal government budget constraint. The first aspect relies on a more controversial mechanism which has been stressed by the literature around what has become known as the fiscal theory of the price level.[1] Specifically, in a world where "non-Ricardian" policy regimes, i.e. policy rules which do not guarantee that the intertemporal government budget constraint is satisfied regardless of how fiscal surpluses and the price level evolve, are possible, the fiscal theory establishes that the specification of fiscal policy matters for the (inflationary) consequences of monetary policy. This view has been criticized along various dimensions. Kocherlakota and Phelan (1999) condense the discussion to a single issue, the assessment of the government's intertemporal budget constraint. Following these authors' interpretation, the fiscal theory of the price level takes the intertemporal budget constraint as a mere *equilibrium condition*, requiring that imbalances between the real value of government debt and future primary surpluses be corrected by adjustments in the price level that lead back to equilibrium. Conversely, the traditional view interprets the intertemporal budget constraint as a *constraint on policy*; according to this position, policy rules that do not satisfy the intertemporal budget constraint for *any* sequence of prices are not feasible and thus a misspecification.

While the debate on the fiscal theory remains unsettled, the present paper adopts an alternative approach, which on the one hand is in line with the traditional view that admits only Ricardian policies, but on the other hand generates results similar to those proposed by the fiscal theory. To arrive there, we borrow from two distinct branches of the literature. The first one is given by the fiscalist approaches to the question of price level determination in dynamic general equilibrium economies already mentioned above. Starting with the seminal contribution by Sargent and Wallace (1981), this literature has found that the behavior of fiscal policy may impose restrictions on what monetary policy can achieve and has identified the intertemporal government budget constraint as the crucial building block that makes monetary and fiscal policies interdependent. However, models of this sort are generally tacit about how the policies considered actually come about and whether they are sustainable. These issues are taken up by another line of macroeconomic research, which considers models of monetary and fiscal policy where policy choices are the result of explicit optimization exercises with well-defined constraints. The drawback with these contributions is that they are generally based on the assumption that there is only one entity which effectively decides about the complete set of policy instruments. Alternatively, when the focus of their analyses is on monetary (fiscal) policy, it is essentially assumed that fiscal (monetary) policy is absent or exogenously given to the model. The consequence is that such models offer only limited insights into dynamic monetary-fiscal interactions.

Against this background, we present a dynamic general equilibrium model of policy making which allows for two institutions commissioned with the conduct of

[1] A selection from the large variety of papers that develop this theory includes e.g. Leeper (1991), Sims (1994) or Woodford (2001).

policy. Specifically, we analyze a simple monetary economy with flexible prices and formalize a policy game between two independent authorities: a fiscal authority and a monetary authority. The starting point for our analysis is a related model proposed by Díaz-Giménez et al. (2006). These authors analyze from an optimal taxation perspective the burden that is caused by nominal debt in a dynamic economy without capital. With a particular specification of preferences[2] and with a single policy authority controlling the complete set of available policy instruments, their central findings are as follows: As long as there are positive amounts of nominal government debt, the ex-post incentive under sequential policy implementation to reduce the real value of outstanding debt through inflation creates a time consistency problem. In the rational expectations equilibrium, these inflationary incentives are anticipated by the public and thus increase the cost of the outstanding debt by creating nominal interest rate distortions. Therefore, the optimal policy without commitment is to progressively deplete the outstanding stock of debt until the extra liability costs vanish. The authors' general message thus is that, with nominal debt and sequential policy making, the optimal debt management policy will differ from the prescriptions of standard Ramsey-optimal taxation in that also the marginal gain from manipulating the real value of the existing debt is explicitly taken into account.

In chapter one, we have extended the framework from Díaz-Giménez et al. (2006) to a model featuring dynamic interaction between two benevolent agencies, a monetary and a fiscal authority. The key finding there is that the decentralization of authority over the relevant policy variables, the supply of money balances and a linear consumption tax, can potentially coordinate the public's expectations in a way that has important implications for the dynamic evolution of the economy. In particular, the rational expectations equilibrium from the case of a single, monolithic policy maker is no longer the only equilibrium, and the associated inflation bias may disappear even for positive levels of outstanding government debt. The reason for this result is that, although the two authorities share the same objective, the presence of the autonomous fiscal policy maker who is not per se subject to the monetary time inconsistency problem allows for a coordination failure among the two independently operating agencies. As a consequence, the economy is in a situation of multiple (Markov-perfect) equilibria, and the equilibrium outcome reported in Díaz-Giménez et al. (2006) is complemented by a welfare superior equilibrium outcome which is not subject to the inflation bias arising in the single agency case and which implements an entirely stationary allocation.

The present paper deviates from this benchmark in that we perturb the objective functions of the strategically interacting government authorities. In particular,

[2] Martin (2006) generalizes the results presented in Díaz-Giménez et al. (2006) and illustrates how the particular specification affects the equilibrium outcomes.

we consider two empirically plausible deviations from the case of purely benevolent policy makers: *On the one hand*, we assume a "conservative" central bank which puts excessive weight on an inflationary loss term, but is also responsive to general economic conditions as measured by consumer welfare. Indeed, the institution of a conservative central bank can be interpreted as a response to the fear that the two authorities would have an incentive to coordinate their policies: While interacting authorities with aligned incentives would, in any given period, be tempted to collude and as a consequence succumb to the monetary time consistency problem, equipping the authorities with differing objectives injects a form of disagreement to their interaction which helps to prevent an unfavorable collusion. *On the other hand*, the fiscal authority's behavior is assumed to be governed by its relative impatience, which we see as resulting from dynamic frictions in the political process. This gives rise to profligate fiscal policies and introduces a strategic conflict between the two authorities about the path of the economy. An immediate implication of this strategic conflict is that the perturbed game, unlike the benchmark discussed in chapter one, is characterized by a unique Markov-perfect equilibrium allocation. In a nutshell, the reason is that the dynamic game being played by the two institutions is no longer of a pure coordination nature such that coordination failure can no longer be the source of equilibrium multiplicity.

The strategic game proceeds within the framework of a dynamic general equilibrium model where government policies are implemented sequentially over time, but, in each period, the two authorities move simultaneously. Of course, the timing of events is crucial. In the literature, there seem to be conflicting views.[3] Although some authors, e.g. Beetsma and Bovenberg (1998), argue that fiscal policy is sluggish relative to monetary policy, we stick to a notion of simultaneous moves rather than formalizing the interaction in terms of a dynamic Stackelberg game, where, in each period, the fiscal authority moves first and the monetary authority follows. The justification for this assumption is that the present model abstracts from considerations related to short run stabilization and thus reduces monetary policy to its public finance role. Then, considerations related to the monetary interaction with fiscal variables play only a minor role for "day-to-day" operations, but are essential in shaping policy over the medium and long run when also fiscal policy has some flexibility.

In settings where explicit commitment is not available, it has been investigated whether delegation of authority over policy decisions can help to improve upon the inferior outcomes when policy makers are subject to dynamically inconsistent incentives. Specifically, in the context of Barro-Gordon (1983a,b) type models where monetary policy faces the task of stabilizing output and inflation, the issue of delegation to decision makers with biased incentives has received much attention; Rogoff's

[3]Compare e.g. the discussion in Dixit and Lambertini (2003a).

(1985b) weight-conservative central banker, inflation targets as proposed by Svensson (1997) and incentive contracts for central bankers as proposed by Walsh (1995) are probably the best-known examples. However, all these approaches completely abstract from fiscal policy or take it as exogenously given. The consequence is that these models fail to take into account the dynamic implications arising from the *interaction* of monetary and fiscal policies. Most importantly, while models along these lines provide important insights concerning the optimal design of stabilization policies, they completely ignore the intertemporal government budget constraint. It is this issue that we will focus on in this paper by allowing for a measure of real government debt as an endogenous state variable that can be dynamically manipulated.

This makes it necessary to consider a dynamic general equilibrium model rather than a (static) ad hoc specification. While this comes at some cost in terms of modeling effort, there are a number of important advantages. First, our model allows for true policy interaction in the sense of a dynamic game with a non-trivial state variable played between the two authorities. Second, our model automatically comprises dynamic forward-looking behavior of all agents such that current economic outcomes are influenced by expectations about future policy. We analyze the Markov-perfect equilibrium (MPE) of the dynamic game played between the monetary and the fiscal authority. Our central result for the considered case of a conservative central bank and an impatient fiscal authority is that the latter can strategically exploit the monetary authority's commitment problem, whereby the dynamic inconsistency of monetary policy stems from its ex-post incentives to surprise the public by inflation. This makes the inflation bias unambigously reappear even under interaction and has important implications for the dynamics of government debt. The explanation for why fiscal policy affects inflation even in our otherwise monetarist world is that, although it has no direct impact on inflation, it has a crucial effect on the monetary authority's incentives to generate inflation. It is in this sense that inflation is to be seen as a fiscal phenomenon. Hence, the present paper rationalizes dynamics in line with the implications of the fiscal theory of the price level, though on the basis of a (perturbed) optimal taxation model which does not rely on the off-equilibrium contingencies introduced by non-Ricardian fiscal policies. Moreover, we shed light on the role of monetary conservatism from a novel perspective, being explicit about the costs of the partial commitment afforded by an inflation-averse central bank. Specifically, while conservatism gives rise to a superior commitment capacity not to engage in inflationary expansions, the implication that any given level of real government debt can be sustained at a lower rate of monetary accommodation is internalized by the fiscal authority. Hence, in equilibrium, it runs larger deficits and accumulates more debt which needs to be serviced by means of distortionary government activity and thereby crowds out private consumption.

The rest of the paper is organized as follows. The next section sets up the model and defines a competitive equilibrium for our economy. Then, the following section briefly lays out the structure of the policy game between the monetary and the fiscal authority. Section 4 contains a description of the equilibrium outcomes. While we are able to characterize the MPE of the game analytically, its quantitative implications must be analyzed by numerical methods. Finally, we discuss the institutional implications arising from our analyis before the paper concludes with a review of the related literature and some further remarks. Technical details and an outline of the numerical methods used are delegated to the Appendix.

2.2 The model

We consider a dynamic monetary general equilibrium economy whose basic structure is identical to the one in Díaz-Giménez et al. (2006). The economy is made up of a government sector and a private sector, and as in Lucas and Stokey (1983) there is no capital. The government sector consists of a monetary authority and a fiscal authority who take their decisions independently. The policy instrument controlled by the monetary authority is the supply of money M^g_{t+1} (the superscript g is used to distinguish an aggregate variable from an individual variable where necessary). The fiscal authority collects consumption taxes τ^c_t in order to finance an exogenously given stream of public expenditures g_t. For simplicity, we let public spending be deterministic and constant over time such that $g_t = g$ for all $t \geq 0$.[4] The two authorities interact via the consolidated budget constraint of the government sector. Seignorage revenues from money creation by the monetary authority accrue to the consolidated government budget. Thus, we restrict attention to the public finance role of monetary policy in order to focus on the implications of decentralized decision power among the two independent institutions. Finally, we assume that the fiscal authority, besides its tax policy, issues nominal one-period bonds B^g_{t+1}, whereby the quantity of bonds traded is determined by the following flow budget constraint for the government sector which has to be satisfied for all $t \geq 0$:

$$M^g_{t+1} + B^g_{t+1} + P_t \tau^c_t c_t \geq M^g_t + B^g_t(1 + R_t) + P_t g \tag{2.1}$$

Here, P_t is the price level prevailing at time t, while R_t is the nominal interest rate paid on the bonds issued at date $t-1$. The initial stock of money M^g_0 and the

[4]What ultimately matters for the construction of our equilibria are the fiscal deficits over time. While the empirical evidence suggests that over short time horizons fiscal adjustments are brought about by changes in government spending rather than in taxation, it turns out that endogenizing taxation is conceptionally more straightforward than endogenizing spending. Therefore, we introduce fiscal discretion with respect to the size of deficits as stemming from variable taxation with government spending given exogenously.

initial debt liabilities $B_0^g(1+R_0)$ are given. However, we impose the additional consistency condition that, in equilibrium, there is no surprise inflation in the initial ($t=0$) period; thus, by linking the nominal interest rate R_0 to the equilibrium rate of inflation in the first period, we prevent the authorities from taking advantage of the inelasticity of the amount of oustanding nominal balances M_0 and B_0 in the first period.[5]

On the private side, the economy is inhabited by a continuum of identical infinitely-lived households whose preferences over sequences of consumption c_t and labor n_t can be represented by the following expression:

$$\sum_{t=0}^{\infty} \beta^t \left\{ u(c_t) - v(n_t) \right\}, \tag{2.2}$$

where the discount factor β satisfies $0 < \beta < 1$. In what follows, we will assume $u(c_t) = log(c_t)$ and $v(n_t) = \alpha n_t$.[6] Each consumer faces the following budget constraint:

$$M_{t+1} + B_{t+1} \leq M_t - P_t(1+\tau_t^c)c_t + B_t(1+R_t) + W_t n_t, \tag{2.3}$$

where W_t is the nominal wage and B_{t+1} and M_{t+1} are nominal government debt and nominal money balances taken over from period t to period $t+1$. We assume that each consumer faces a no-Ponzi condition that prevents him from running explosive consumption/debt schemes:

$$lim_{T\to\infty} \beta^T \frac{B_{T+1}}{P_T} \geq 0 \tag{2.4}$$

As a shortcut for introducing a well-defined money demand we assume that the gross-of-tax consumption expenditure in period t must be financed using currency carried over from period $t-1$, which gives rise to the following cash-in-advance (CIA) constraint:

$$M_t \geq P_t(1+\tau_t^c)c_t \tag{2.5}$$

The timing protocol underlying this CIA constraint follows Svensson (1985) and requires that the goods market operates and closes before the asset market opens.

[5] The rational expectations consistency condition for the initial period is imposed because it facilitates a meaningful welfare comparison across different monetary and fiscal institutions.

[6] The assumption of linear disutility of labor is made to sharpen the discussion, but implies also that the government sector cannot affect the real interest rate. In contrast, the assumption of log utility from consumption is essential because it allows to focus on the role of nominal debt as a source of time inconsistency rather than on the effects due to private holdings of nominal money balances. That is, we abstract from seignorage on base money and focus on the implications of changing the real value of nominal debt. Importantly, this focus is consistent with the situation in most developed economies where government debt is arguably more important than money holdings as a source of dynamically inconsistent incentives. See also Nicolini (1998) for an instructive exposition of the nature of the time inconsistency of monetary policy and Martin (2006) for results with a more general specification of preferences.

This implies that unexpected monetary expansions, due to the inflationary pressure they cause, are distortionary because the nominal asset portfolio cannot be reshuffled in response to monetary innovations and only the money balances taken over from the previous period are available to facilitate current consumption purchases.

The productive side of the model economy is very simple since there is no capital. In each period, labor n_t can be transformed into private consumption c_t or public consumption g at a constant rate, which we assume to be unitary. Then, the equilibrium real wage is $w_t \equiv \frac{W_t}{P_t} = 1$ for all $t \geq 0$, and aggregate feasibility is reflected by the following linear resource constraint:

$$c_t + g \leq n_t \tag{2.6}$$

We are now ready to define a competitive equilibrium for given government policy choices $\{\tau_t^c, M_{t+1}^g, B_{t+1}^g, g\}_{t=0}^{\infty}$.

Definition 2.1 *A competitive equilibrium for this economy is composed of the government sector's policies* $\{\tau_t^c, M_{t+1}^g, B_{t+1}^g, g\}_{t=0}^{\infty}$*, an allocation* $\{c_t, n_t, B_{t+1}, M_{t+1}\}_{t=0}^{\infty}$*, and prices* $\{R_{t+1}, P_t\}_{t=0}^{\infty}$ *such that:*

1. *given* $B_0^g(1 + R_0)$ *and* M_0^g*, the policies and the prices satisfy the sequence of budget constraints of the government sector described in expression (2.1);*

2. *when households take* $B_0(1+R_0)$*,* M_0 *and prices as given, the allocation solves the household problem of maximizing (2.2) subject to the private budget constraint (2.3), the CIA constraint (2.5) and the no-Ponzi condition (2.4);*

3. *markets clear, i.e.:* $B_t^g = B_t$*,* $M_t^g = M_t$*, and* g *and the allocation satisfy the economy's resource constraint (2.6) for all* $t \geq 0$*.*

On the basis of our assumptions on household preferences, it is straightforward to show that in the competitive equilibrium allocation of this economy the household budget constraint (2.3) and the aggregate resource constraint (2.6) are both satisfied at equality. Moreover, the first order conditions of the Lagrangean representing the household's constrained optimization problem are both necessary and sufficient conditions to characterize the solution to the household problem. Finally, when $R_{t+1} > 0$, the CIA constraint (2.5) is binding, and the competitive equilibrium allocation for given government policies can be determined from the government budget constraint (2.1), the aggregate resource constraint (2.6) and the following conditions that must hold for all $t \geq 0$:

$$M_t = P_t(1 + \tau_t^c)c_t \tag{2.7}$$

$$\frac{u'(c_t)}{v'(n_t)} = (1 + R_t)(1 + \tau_t^c) \tag{2.8}$$

$$(1 + R_{t+1}) = \frac{v'(n_t)}{\beta v'(n_{t+1})} \frac{P_{t+1}}{P_t} \tag{2.9}$$

$$lim_{T \to \infty} \beta^T \frac{M_{T+1} + B_{T+1}}{P_T} = 0 \tag{2.10}$$

2.3 The policy game

The foregoing definition of a competitive equilibrium is conditional on an arbitrary sequence of government policies. Given that our focus is on an environment where there is no explicit commitment technology, pinning down these policies requires the identification of a policy rule that is sequentially optimal from the two authorities' perspectives. As hinted in the Introduction, the presence of nominal government debt gives rise to an inflationary bias due to the ex-post incentives to deflate the real value of outstanding liabilities. This problem is institutionally dealt with by delegation of decision power over monetary policy to a "conservative" monetary authority whose objective function differs from the representative agent's welfare in a fashion to be detailed below. Since the authority over fiscal policy remains with the original government entity, we are in a situation of decentralized authority. Hence, we define a policy rule to be the combination of a fiscal and a monetary policy rule; each of these latter rules is determined independently by the corresponding institution $i = f, m$, respectively. Absent intertemporal commitment, policies are implemented sequentially, whereby we limit the analysis to Markov-stationary policy rules, i.e. time-invariant mappings returning policy choices as a function of the current state of the economy.[7] In order to identify the equilibrium policy rule, we therefore need to find the optimal time-invariant strategies in the strategic game between the two authorities. A formal description of the game-theoretic structure of the two authorities' interaction is given in Appendix B.3. Here, it suffices to mention that (i) in view of their differing objectives, the two authorities choose their policies in a non-cooperative manner, and that (ii) in doing so, they take as given not only the public's formation of expectations, but also the policy rules employed by their future incarnations as well as their respective opponent's current play. Hence, the appropriate equilibrium concept for the simultaneous moves stage game interaction is Nash.[8] We denote the policy function by $\varphi(z^g) = (\varphi_f(z^g), \varphi_m(z^g))$, where $\varphi_f(z^g)$ and $\varphi_m(z^g)$ are the fiscal and monetary parts of the rule. They give the respective

[7]The implication is that history does not matter except via its influence on the current state. It is precisely this restriction that rules out reputational mechanisms.

[8]One might want to argue that communication between monetary and fiscal authorities renders the non-cooperative outcomes of Nash play implausible. Note however that, as long as formal contracts are unavailable, the only self-enforcing plans (in the sense of correlated equilibria) that players could implement under direct communication would be randomizations among the Nash equilibria of the non-cooperative game; compare Myerson (1991), chapter 6.

policy instruments τ^c and M' as functions of the *aggregate state* $z^g \equiv \frac{B^g(1+R)}{M^g}$, which is informative along two dimensions: First, with respect to the composition of the nominal claims with which households enter period t, and secondly, with respect to the real value of the government debt burden inherited from the past.[9]

The data of the economy introduced so far are sufficient to characterize a competitive equilibrium for a sequence of arbitrary policy choices. What is lacking to pin down these policy choices are (i) the preferences of the two policy making authorites as represented by their objective functions, and (ii) an appropriate definition of a game-theoretic equilibrium. We now turn to the former issue. Let $U(z, z^g; \varphi)$ be the lifetime utility enjoyed by a household with individual state z when the aggregate state is z^g and the policy rule employed by the two authorities is φ. The fiscal authority is impatient insofar as it tries to maximize the discounted sum of the household's period utilities $u(c_t) - v(n_t)$, whereby its discount factor $\delta < \beta$ is distorted downwards as compared to the one employed by the representative household. The fiscal objective function is:

$$\sum_{t=0}^{\infty} \delta^t \{u(c_t) - v(n_t)\}$$

We see this payoff function as a shortcut for introducing politico-economic frictions into the model. Examples include electoral concerns or fiscal institutions that disperse the decision power over debt and deficits.[10] A divergence in the discount

[9]To understand why z^g serves as the aggregate state variable, notice that neither nominal variables such as money and bonds nor their real values are sufficient statistics. The reason is that the contemporaneous price level, being endogenous, cannot be used to normalize nominal variables. Moreover, due to the CIA constraint only money is available for current consumption expenditure such that we need information on the composition of the nominal asset portfolio held by private agents. Finally, to appropriately reflect the real debt burden inherited from the past, also the interest payments on maturing bonds must be accounted for.

[10]In a related context, Beetsma and Bovenberg (1999) introduce such frictions as the result of special-interest politics. Persson and Tabellini (2000), chapter 13, provide an extensive review of the politico-economic literature on the accumulation of public debt. The main arguments evolve around the notion of "divided government" and political instability. The first issue can lead to a dynamic common pool problem with too much spending occurring too soon or to delayed stabilization as a consequence of a war of attrition. The second line of research stresses the strategic calculus of governments who accumulate debt in order to increase their reelection probability or to affect incentive constraints faced by their successors or political opponents. While most of these models are formulated in terms of variable government spending, the obvious result with exogenous spending is that political incentives map into myopic policy choices which attach too much weight to the present as opposed to the future. A possible way of modelling such fiscal behavior would be to let the fiscal authority be engaged in quasi-geometric discounting. However, such a specification on its own gives rise to a dynamic game between the subsequent incarnations of the fiscal authority, which is sufficiently difficult to analyze already in isolation; compare e.g. Krusell, Kuruscu and Smith (2000, 2002). Therefore, we choose to model the bias towards the present as simply emerging from a lower discount factor.

factors of the form $\delta < \beta$ then reflects the systematic tendency towards myopic policy choices. We let $V(z^g; \varphi)$ denote the fiscal value function associated with a given aggregate state z^g and policy rule φ.

As regards the monetary authority, our starting point are the statutes of many independent central banks which ascribe importance to the task of curbing inflation or alternatively stabilizing the price level, but at the same time also refer to further indicators for general economic performance. For example, the "Protocol on the Statute of the European System of Central Banks and of the European Central Bank"[11] prescribes the following objectives for the European monetary authority (Article 2): *"... the primary objective of the E[uropean] S[ystem] [of] C[entral] B[anks] shall be to maintain price stability. Without prejudice to the objective of price stability, it shall support the general economic policies in the [European] Community with a view to contributing to the achievement of the objectives of the Community... The ESCB shall act in accordance with the principle of an open market economy with free competition, favouring an efficient allocation of resources ..."*. We parameterize this by defining the monetary authority's objective function as follows:

$$\sum_{t=0}^{\infty} \beta^t \left\{ -\gamma \left(\frac{P_t}{\bar{P}_t} \right)^2 + (1-\gamma)[u(c_t) - v(n_t)] \right\}$$

Here, $\gamma \in (0, 1)$ is a weight which balances the relative impacts on the monetary authority's payoff of general welfare (as measured by the representative household's lifetime utility) and a loss term resulting from unanticipated deviations of the realized price level P from the level $\bar{P}$ that was expected by the public. This specification is a particular interpretation of a weight-conservative central banker (Rogoff, 1985b), according to which the monetary aversion against *surprise* inflation implies a reluctance to use the inflation tax as a lump-sum instrument. This monetary objective captures two important points in line with real world evidence: First, the monetary authority has an explicit interest in price level stability; and secondly, despite its specific mission, the monetary authority cares also about general economic conditions.[12] On the basis of this specification for period payoffs, we define the value function for the monetary authority as $W(z^g; \varphi)$.

Finally, our relevant concept to pin down policy choices is Markov-perfect equilibrium (MPE). Accordingly, the main goal is to identify a policy rule $\varphi(z^g)$ that is time consistent. This means that the authorities must not have an incentive to deviate from this rule when they choose their policy instruments simultaneously and

[11] Protocol annexed to the Treaty establishing the European Community. See European Central Bank (2000).

[12] While the monetary objective function is stipulated in an ad hoc way, it seems natural in the present environment featuring a monetary time consistency problem. Compare also the literature on central bank contracts, e.g. Walsh (1995).

sequentially over time. Finding such a policy rule involves three steps:[13]

1. Define the economic equilibrium for arbitrary policy rules φ. This allows to determine the representative household's welfare level as well as the authorities' value functions for arbitrary policy rules φ.

2. Define the optimal equilibrium policy π in the current period when future policies are determined by some arbitrary policy rule φ. Since the optimal current policy depends on the current states, this step determines the optimal current policy rule $\pi(\varphi)$, given a future rule φ.

3. Define the conditions under which the authorities will not deviate from the rule assumed for the future, i.e. impose time consistency on the policy rule. Time consistency will obtain if the policy rule assumed for the future is equal to the rule that is optimal in the current period (policy fixed point): $\varphi = \pi(\varphi)$.

With this structure the policy equilibrium can be represented recursively. Recall that in our deterministic model with constant government expenditure, the aggregate state is simply z_t^g; the individual state is given by z_t. We now operationalize the three steps described above; details of the procedure are specified in the Appendix.[14]

2.3.1 Equilibrium for arbitrary policy rule

Conditional on a policy rule φ employed by the two authorities, a competitive equilibrium is defined in the usual way. In the rational expectations equilibrium, a fixed point between a perceived law of motion $G^e(z^g;\varphi)$ for the endogenous aggregate state variable z^g and the induced actual law of motion $G(z^g;\varphi)$ has to obtain. This allows us to recast the definition of a competitive equilibrium in a recursive manner.

Definition 2.2 *A recursive competitive equilibrium for given policies φ consists of a household value function $U(z, z^g;\varphi)$, (individual) decision rules $\{c(z, z^g;\varphi), n(z, z^g;\varphi), B'(z, z^g;\varphi), M'(z, z^g;\varphi)\}$ and an aggregate function $G^e(z^g;\varphi)$ such that:*

1. *households optimize, i.e. given the states (z, z^g), policies φ and a perceived law of motion $G^e(z^g;\varphi)$, the value function $U(z, z^g;\varphi)$ and the decision rules $\{c(\cdot), n(\cdot), B'(\cdot), M'(\cdot)\}$ solve the household problem;*

[13] The procedure has been developed by Klein, Quadrini and Ríos-Rull (2005) who apply it to analyze a model of international tax competition.

[14] The equations presented in the following are derived from a primal approach to the authorities' problems; the respective problems are conditional on the other authority's policy rule as well as on private expectations as represented by the barred variables in the constraints. The primal approach reformulation of the relevant decision problems is done in Appendix B.2.

2. the perceived law of motion is the actual law of motion, i.e. households are representative and form rational expectations:

$$z' = z'^g = G^e(z^g; \varphi)$$

3. the pursued policies are feasible, i.e. the consolidated budget constraint of the government sector is satisfied in every period:

$$M'^g + B'^g + P\tau^c c = M^g + B^g(1+R) + Pg.$$

The optimal household decisions in view of a policy rule φ determine the household value function $U(z, z^g; \varphi)$. By the same token, once the actual law of motion $G(z^g; \varphi)$ consistent with policy rule φ is determined, we can infer the fiscal value function, conditional on the policy rule φ:

$$\begin{aligned} V(z^g;\varphi) &= \{[log(c(z^g;\varphi)) - \alpha(c(z^g;\varphi)+g)] + \delta V(z'^g;\varphi)\} \\ \text{s.t.} &\quad \frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'^g}{(1+\mu(z'^g;\varphi))} - c(z^g;\varphi) - \frac{\beta}{\alpha}\frac{z^g}{(1+\mu(z^g;\varphi))} = 0, \end{aligned}$$

where $\mu \equiv \frac{M'^g}{M^g} - 1$ is the rate of money expansion determined by the monetary authority. Similarly, for the monetary authority, we have:

$$\begin{aligned} W(z^g;\varphi) &= \left\{-\gamma\left(\frac{\bar{c}(z^g)(1+\bar{\tau}^c(z^g))}{c(z^g;\varphi)(1+\tau^c(z^g;\varphi))}\right)^2 + (1-\gamma)[log(c(z^g;\varphi)) - \alpha(c(z^g;\varphi)+g)] + \beta W(z'^g;\varphi)\right\} \\ \text{s.t.} &\quad \frac{\beta}{\alpha} - g + \beta z'^g c(z'^g;\varphi)(1+\tau^c(z'^g;\varphi)) - c(z^g;\varphi) - z^g c(z^g;\varphi)(1+\tau^c(z^g;\varphi)) = 0, \end{aligned}$$

where barred variables denote predetermined private expectations.

2.3.2 Optimal current policy rule for given future policy rule

We look for a MPE where both authorities correctly anticipate their current opponent's as well as their successors' policy choices and take them as given. Clearly, the optimal control laws depend on each other, but in the MPE with simultaneous moves each authority ignores the influence that its choice exerts on the other authority's current choice. Then each authority faces a situation where its own current policy choice affects both its current payoff and its continuation value from the next period onwards. The contemporaneous effect reflects the impact of this period's allocation and prices on the period payoff. The effect on the continuation value works through two channels both of which hinge on the real value of liabilities z'^g that result at the beginning of the subsequent period as a consequence of the current policies implemented by the two authorities: First, z'^g is a measure of the government sector's indebtedness with the private sector and therefore determines the amount of future distortionary activity necessary to balance the intertemporal government budget; this channel reflects a distortion smoothing motive. Second, the future authorities' incentives to implement a particular policy are a function of the future state z'^g. Hence, by manipulating the future state z'^g, the current policy makers can affect the continuation play; this channel reflects a strategic manipulation motive.[15]

Let $\pi = (\pi_f, \pi_m)$ denote the current policy rule, and let $\varphi = (\varphi_f, \varphi_m)$ denote the future policy rule. Individual households take these rules as given. With the appropriate notational changes, a recursive competitive equilibrium for arbitrary current policy actions π followed by a future policy rule φ is then defined analogously to above recursive competitive equilibrium for given policies φ. Faced with a continuation policy rule φ, the authorities' problem consists of optimally determining their contemporaneous policies π. Specifically, for the fiscal authority, we have the following (in order to distinguish it from the continuation value $V(z'^g;\varphi)$, the current value $\hat{V}(z'^g;\pi,\varphi)$ is denoted with a hat):

$$\hat{V}(z^g;\pi,\varphi) = max_{\pi_f}\left\{[log(c(z^g;\pi)) - \alpha(c(z^g;\pi)+g)] + \delta V(z'^g;\varphi)\right\},$$

where the maximization is subject to the fiscal implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'^g}{(1+\mu(z'^g;\varphi))} - c(z^g;\pi) - \frac{\beta}{\alpha}\frac{z^g}{(1+\mu(z^g;\pi_m))} = 0$$

For the monetary authority, we have:

$$\hat{W}(z^g;\pi,\varphi) =$$
$$max_{\pi_m}\left\{-\gamma\left(\frac{\bar{c}(z^g)(1+\bar{\tau}^c(z^g))}{c(z^g;\pi)(1+\tau^c(z^g;\pi_f))}\right)^2 + (1-\gamma)[log(c(z^g;\pi)) - \alpha(c(z^g;\pi)+g)] + \beta W(z'^g;\varphi)\right\},$$

where the maximization is subject to the monetary implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta z'^g c(z'^g;\varphi)(1+\tau^c(z'^g;\varphi)) - c(z^g;\pi) - z^g c(z^g;\pi)(1+\tau^c(z^g;\pi_f)) = 0$$

Note that the authorities maximize directly over their current policies (π_f and π_m, respectively), whereby the authorities understand their policies' impact on the ensuing private allocation. This effect is captured by deriving the authorities' value functions from the private allocation which, in turn, is conditional on policies. The

[15]However, it is important to realize that each current authority $i = f, m$ and its respective subsequent incarnation agree along the following dimension: *Given* current expectations about the continuation play as reflected by the nominal interest rate R which households demand as a compensation for buying government debt, there is no conflict about how to set the next period's policies. The disagreement between current and future policy makers stems only from the fact that the former can manage the public's expectations with respect to the continuation play φ, while the latter cannot.

authorities make their current policy choices simultaneously, taking the other one's policy rule as well as the future continuation play as given. The fiscal authority, given π_m and $\varphi = (\varphi_f, \varphi_m)$, chooses π_f to maximize $\hat{V}(z^g; \pi, \varphi)$, and the monetary authority, given π_f and $\varphi = (\varphi_f, \varphi_m)$, chooses π_m to maximize $\hat{W}(z^g; \pi, \varphi)$. This leads to the following definition:

Definition 2.3 *Given the functions $\varphi = (\varphi_f, \varphi_m)$, a Nash equilibrium of the policy game is a pair of functions $\{\pi_i^*(z^g; \varphi)\}_{i=f,m}$ such that (i) $\pi_f^*(z^g; \varphi)$ maximizes $\hat{V}(z^g; \pi, \varphi)$, given $\pi_m^*(z^g; \varphi)$, and (ii) $\pi_m^*(z^g; \varphi)$ maximizes $\hat{W}(z^g; \pi, \varphi)$, given $\pi_f^*(z^g; \varphi)$.*

By construction, the Nash equilibrium will consist of feasible policies. However, out of equilibrium, the payoffs may not be well-defined. This will be the case for policy choices which are jointly incompatible with a competitive equilibrium. Then, the question is what will happen out of equilibrium. Noting that the described environment and the rules according to which the two authorities interact in this environment fall short of the formal description of a game, we will nevertheless proceed to analyze the MPE outcomes.[16]

2.3.3 Policy fixed point

Now, we can define the equilibrium time consistent policies:

Definition 2.4 *The policy functions $\varphi = (\varphi_f, \varphi_m)$ define time consistent policies if they are the Nash solution of the policy game when the two authorities expect φ to determine future policies. Formally: $\varphi_i(z^g) = \pi_i(z^g; \varphi)$, $i = f, m$.*

A MPE of the policy game described above is a profile of time consistent Markov strategies for the two authorities that yields a Nash equilibrium in every proper subgame. It is these time consistent policies φ and the associated equilibrium outcomes that we are interested in.

[16]Formally, the structure presented is a quasi-game. The problem is that the outcome and the associated payoffs are not well-defined if there is no feasible allocation satisfying a consistency condition defined by equation (2.11) below. In such situations, the authorities' policy choices τ^c and M' are incompatible with a competitive equilibrium. In a related context, but with only one authority, a possible solution to this lack of formal structure has been suggested by Bassetto (2002, 2005) who proposes the introduction of an explicit market microstructure and the adoption of a modified notion of government policy within a period as contingent strategy rather than as uncontingent plan.

2.4 Markov-perfect equilibrium outcomes

2.4.1 Necessary conditions

Before characterizing the MPE outcomes associated with the dynamic policy game, at a more fundamental level existence and uniqueness of such a MPE should be verified. As regards the former issue, we can build on an existence result in chapter one which establishes that a differentiable MPE in stationary strategies exists for the infinite-horizon game at hand. However, in contrast to the benchmark case discussed in chapter one, multiplicity of equilibrium outcomes will not be a concern here, if we restrict the analysis to differentiable policy rules. The reason is that, in the present context, the two policy authorities' objectives are conflicting. In particular, as will become obvious in a moment, the fiscal authority's impatience forces monetary policy to be accommodative in the sense of (partially) monetizing fiscal deficits. This results in anticipated inflationary distortions, whose degree is marginally responsive to variations in z^g, and implies that there is no scope for the favorable coordination of the public's expectations that was the condition for sustaining a stationary non-inflationary MPE in the benchmark case of chapter one.

Concentrating on differentiable Markov strategies, it is useful to present the two authorities' first order conditions with respect to their *primal* choice variables c and z' for a given continuation policy φ (step 2 above). These first order conditions, together with the respective implementability constraints, are necessary conditions characterizing any MPE.[17] Moreover, in any MPE, the following consistency condition, which guarantees that the two authorities' dynamic programs and their respective solutions are mutually consistent and decentralizable as a competitive equilibrium, must hold:

$$c(1+\tau^c(z;\varphi))(1+\mu(z;\varphi)) = \frac{\beta}{\alpha} \tag{2.11}$$

The fiscal authority's optimality conditions with respect to c and z' can be combined to yield the following expression:

$$\frac{1}{c} - \alpha = -\frac{\frac{\delta}{\beta} V'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))} \left[1 - \varepsilon_\mu(z';\varphi)\right]^{-1}, \tag{2.12}$$

where $\varepsilon_\mu(z;\varphi) \equiv \frac{\partial(1+\mu(z;\varphi))/\partial z}{(1+\mu(z;\varphi))/z}$ is defined to be the elasticity of (gross) monetary expansions in response to changes in the aggregate state z. According to this condition, the marginal gain from increased current consumption is equated to the marginal cost of entering the next period with a higher stock of real debt z', which is (i) scaled

[17] The relevant equations are derived in Appendix B.5. In what follows, we will drop the superscript g because in any rational expectations equilibrium, the individual state z and the aggregate state z^g must coincide.

down by the factor $\frac{\delta}{\beta} < 1$ due to the fiscal authority's relative impatience and (ii) scaled up by the factor $[1-\varepsilon_\mu(z';\varphi)]^{-1} \geq 1$.[18] This latter amplification results from the adverse expectational effects of increased outstanding liabilities: A higher debt burden increases the future monetary authority's incentives to resort to the inflation tax, which is anticipated by the public and leads to an upward distortion in nominal interest rates; this, in turn, constitutes an opportunity cost of consumption due to the CIA constraint. That the fiscal authority will not only behave impatiently, but will also take into account future incentive problems in formulating its distortion smoothing policy becomes even more apparent if an envelope condition is applied in order to substitute for the value function term in (2.12), which yields:

$$\frac{1}{c} - \alpha = \frac{\delta}{\beta}\left(\frac{1}{c(z';\varphi)} - \alpha\right)[1-\varepsilon_\mu(z';\varphi)]^{-1} \tag{2.13}$$

Equation (2.13) reveals that, even though the current fiscal authority is not per se subject to a time consistency problem, it will not act like a conventional Ramsey planner. Rather, in trying to smooth distortions over time, it will also take into account the incentive problems of future policy makers. However, since the fiscal authority attaches a lower relative weight to the time when the commitment problem is relevant, this strategic rationale is discounted.

As for the fiscal authority, the monetary authority's first order conditions for c and z' can be combined to yield a single expression:

$$\frac{2\gamma\frac{1}{c} + (1-\gamma)\left(\frac{1}{c} - \alpha\right)}{[1 + z(1+\tau^c(z;\varphi))]} = -\frac{W'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))}[1-\varepsilon_\mu(z';\varphi)]^{-1} \tag{2.14}$$

Again, this condition has the interpretation that, in each period, the monetary authority tries to equate the marginal gain from higher current consumption to the marginal cost associated with higher debt in the next period. The marginal benefit from current consumption as perceived by the monetary authority (LHS) consists of three components: First, there is the direct effect via current household utility as reflected by the expression $(1-\gamma)\left(\frac{1}{c} - \alpha\right)$. Second, for given private sector expectations, higher consumption implies lower surprise inflation and hence impacts on the inflationary loss term. Finally, the expression in the denominator (which exceeds one for $z > 0$) reflects a discounting of the benefits from increased consumption due to the following mechanism: By virtue of the CIA constraint, higher consumption requires that the current monetary policy maker has to forego the inflation tax,

[18]The equilibrium property $[1-\varepsilon_\mu(z';\varphi)]^{-1} \geq 1$ follows from the fact that $1 > \varepsilon_\mu(z';\varphi) \geq 0$. In particular, since any competitive equilibrium must be decentralized via distortionary policies, we have $[u'(c(z)) - v'(c(z)+g)] = \left(\frac{1}{c(z)} - \alpha\right) > 0$ for all $z \geq 0$; then, as seen from (2.13), compatibility with fiscal optimality requires $1 > \varepsilon_\mu(z';\varphi)$. Finally, $\varepsilon_\mu(z;\varphi) \geq 0$ is a consequence of the monetary authority's incentives to monetize outstanding government liabilities via the inflation tax being a non-decreasing function of the inherited debt burden z. In Proposition 1 below, we will verify that $\varepsilon_\mu(z;\varphi) > 0$.

which would operate in a lump-sum fashion on the outstanding liabilities; rather, the policy maker leaves its successors with the task to satisfy the intertemporal budget constraint by means of future distortionary activity. The evaluation of the marginal cost of higher debt in the next period again takes into account the commitment problems of future policy makers such that the RHS comprises the amplification term $[1-\varepsilon_\mu(z;\varphi)]^{-1} \geq 1$. Substitution of the value function derivative via an envelope condition leads to the following intertemporal expression:

$$\frac{2\gamma\frac{1}{c}+(1-\gamma)\left(\frac{1}{c}-\alpha\right)}{(1+z(1+\tau^c(z;\varphi)))} \tag{2.15}$$
$$= \left[\frac{2\gamma\frac{1}{c(z';\varphi)}+(1-\gamma)\left(\frac{1}{c(z';\varphi)}-\alpha\right)}{[1+z'(1+\tau^c(z';\varphi))]} - \frac{2\gamma\frac{\varepsilon_\mu(z';\varphi)}{z'}}{c(z';\varphi)(1+\tau^c(z';\varphi))}\right][1-\varepsilon_\mu(z';\varphi)]^{-1},$$

which dictates distortion smoothing subject to the twofold incentive constraint stemming from debt being nominal and policy implementation being sequential. The former distortion, reflecting the discretionary incentive to reduce the real value of government debt, enters (2.15) via the term $[1+z(1+\tau^c(z;\varphi))]$, as explained above. The latter distortion arises as a consequence of future policies being responsive to the inherited stock of liabilities z' and the fact that a non-myopic policy maker takes into account that this will be rationally anticipated by the public.

Explicitly solving for the allocation implemented as the outcome of the dynamic interaction among the sequence of monetary and fiscal policy makers necessitates numerical methods the details of which are specified in Appendix B.7. In order to illustrate the dynamic evolution of the economy in the presence of nominal government debt, we will invoke a simple numerical example. For that purpose, we choose the following values for the parameters of our model economy: $\alpha = 0.45$, $\beta = 0.98$, $\gamma = 0.5$, $b_0 \equiv \frac{z_0}{(1+R_0)} = 1.28$, $g = 0.5$. These parameter values largely draw on Díaz-Giménez et al. (2006) in order to make our results comparable to their ones. However, we choose the values for initial government debt and public spending more in line with recent OECD data.[19] Finally, the fiscal discount factor δ is set equal to 0.95 ($< \beta$), reflecting the assumed impatience underlying the conduct of fiscal policy.

2.4.2 Economic outcomes and institutional implications

To understand the MPE outcomes of the policy game considered here, the insights from the benchmark case, where the fiscal discount factor is not perturbed ($\delta = \beta$) and the monetary authority is not inflation-averse per se ($\gamma = 0$), are helpful. In this

[19]In 2003, the average of general government gross financial liabilities across the OECD countries was 76.0% of GDP, while the ratio of general government total outlays to GDP was at 40.7%; compare OECD (2004).

situation, both authorities share the representative household's preferences, but the monetary authority has access to a policy instrument which gives rise to dynamically inconsistent incentives. However, as shown in chapter one, the decentralization of decision power among the two interacting authorities is an institutional arrangement that may help to overcome the time inconsistency problem plaguing monetary policy and the associated inflation bias. The key mechanism sustaining this favorable equilibrium outcome is the fact that the reaction function, which pins down optimal fiscal policy, acts as an additional constraint on monetary policy choices. Consequently, since the optimal fiscal policy is not dynamically inconsistent, there is scope for a favorable coordination of the public's expectations. Given such expectations and a fiscal policy that keeps the stock of real government liabilities z constant, a benevolent monetary policy maker refrains from using the inflation tax. Loosely speaking, the point is that the decentralized decision power among the two authorities does not allow the monetary authority to substitute the distortionary consumption tax by the lump-sum inflation tax. The result is that the standard single-agency MPE outcome, where the stock of debt is driven to zero[20] in order to economize on the extra expectational costs of outstanding nominal liabilities, is complemented by another MPE outcome characterized by (i) a stationary allocation even in the presence of positive amounts of oustanding government debt and (ii) the absence of a systematic inflation bias.

Nevertheless, even in a non-inflationary equilibrium, government debt crowds out private consumption because it has to be serviced via distortionary taxation. Given the adverse welfare implications of government debt in the benchmark model, the following question emerges: Why is there nominal debt at all, if there are no benefits from it,[21] but an outstanding amount of debt only depresses consumption and may additionally give rise to adverse expectational effects? A potential answer to this question can be given if we acknowledge that the fiscal authority's preferences are slightly perturbed. Indeed, if the fiscal authority discounts the future at a higher rate than the private households and the monetary authority do ($\delta < \beta$), then its preferred policy consistently shifts policy distortions into the future at the cost of accumulating public debt. Hence, there emerges a strategic conflict between the two authorities about when to incur the distortions necessary to satisfy the intertemporal government budget constraint. This conflict can be summarized by the two authorities' differing preferences with respect to the path of the endogenous

[20]The convergence to a zero debt level is an implication of the particular logarithmic specification of preferences; see Martin (2006) for a generalization.

[21]Of course, the model is a simplification in this respect. A role for government debt can arise from its tax smoothing potential (Barro, 1979), its interaction with the accumulation of physical capital (Diamond, 1965) as well as from liquidity or insurance services of government bonds in stochastic or incomplete market environments (Aiyagari and McGrattan, 1998; Shin, 2006).

state variable z.[22]

Given that $c(z)$ is strictly decreasing,[23] optimality condition (2.13) reveals that the fiscal authority favors an increasing path of z whenever $\frac{\delta}{\beta}\left[1-\varepsilon_{\mu}(z';\varphi)\right]^{-1}<1$ and vice versa. This stems from the relative impatience inherent in fiscal policy making which is traded off against the welfare losses due to the crowding out of consumption via debt. In the long run, the model predicts a stationary level of debt z^* implicitly characterized by $\frac{\delta}{\beta}\left[1-\varepsilon_{\mu}(z^*;\varphi)\right]^{-1}=1$. For $z<z^*$, the fiscal authority is not willing to balance the budget but prefers to accumulate debt. This means that the selection of a non-inflationary equilibrium necessarily breaks down because of the monetary authority's motive to contain the accumulation of debt, which is achieved by engineering some inflation in order to devaluate the stock of outstanding liabilities. Hence, the monetary ex-post incentives to generate surprise inflation are always present during the transition to z^*. In a rational expectations equilibrium the public anticipates such inflation, and - abstracting from the interference by fiscal polcies - the path of real debt preferred by the monetary authority would be decreasing, a scenario similar to the one described in Díaz-Giménez et al. (2006).

The policies preferred by the two authorities can be qualitatively characterized by inspection of their relevant optimality conditions. However, it is not as straightforward to anticipate the details of how the economy will evolve in equilibrium as an outcome of the dynamic policy interaction. Therefore, we resort to a numerical example which is parameterized as described above. The key results of this exercise are displayed in Figures 2.1 and 2.2. Figure 2.1 shows the dynamic evolution of the end-of-period stock of real government debt $b'=\frac{z'}{(1+R')}$. The stock of real debt grows at a decreasing rate, converging to a debt ceiling at $b^*=\frac{z^*}{(1+R^*)}$. The increasing distortions associated with the accumulation of debt affect the pattern of consumption displayed in Figure 2.2. As hinted above, the debt ceiling is determined by the fiscal optimality condition (2.13); however, it is important to realize that this condition is contingent on the equilibrium policy rule φ and thus depends also on monetary policy.[24] In particular, it must be the case that, at z^*, the losses incurred due to inflation and the benefits from stabilizing the level of debt by monetizing fiscal deficits via the inflation tax are equal from the monetary authority's

[22] The following analyis throughout assumes that the initial state z_0 takes a small positive value such that convergence to the steady state z^* proceeds from below. Convergence from $z_0>z^*$ involves a gradual decumulation of public debt, whereby the monetary inflation tax is operative in the sense of $(1+\mu(z))>1$.

[23] This property is equivalent to a strictly concave value function $V(\cdot)$. The intuition for the concavity is that a higher level of z calls for higher future distortionary activity to balance the intertemporal government budget, which implies a lower continuation path of c, and that increases of z are increasingly costly due to the concavity in c of the representative household's period payoff.

[24] The same argument applies for the monetary optimality condition (2.15), which is contingent on the fiscal behavior stipulated by the equilibrium rule φ.

perspective. A closer analysis of the situation for the monetary authority reveals the following: On the one hand, monetary policy needs to inflate the economy in order to contain the accumulation of debt preferred by the fiscal authority; indeed, the monetary incentives to inflate the economy are a non-decreasing function of the stock of debt. On the other hand, the responsiveness of monetary policy to the level of debt makes the accumulation of debt increasingly unattractive because the dynamically inconsistent incentives are anticipated by the public. Given that also the fiscal authority suffers from the extra distortions caused by these expectational effects, the fiscal authority will have an incentive not to let debt go out of hands.

The mechanism behind these dynamics is that the fiscal impatience undermines the monetary authority's ability to credibly sustain the zero-inflation competitive equilibrium that was available with purely benevolent interacting authorities. Nominal debt now bears liability costs beyond the costs arising from the need to balance the intertemporal government budget by distortionary activity. Consequently, the optimal policy would be to gradually decumulate debt until these extra liability costs vanish. However, the fiscal authority's bias towards the present implies a tendency to accumulate debt. These two effects balance each other at the steady state z^*. Hence, to a certain extent - namely up to the point where the gains from reducing the liability costs of debt via the inflation tax equal the costs to the monetary authority due to actual inflation - fiscal policy indeed dominates monetary policy. Importantly, it can be shown that there cannot be a MPE involving zero inflation during the transition (from below) to the steady state. This is seen by inspection of the monetary authority's first order condition (2.15) which can be rewritten as follows:

$$\begin{aligned} & \frac{W'(z;\varphi)}{c(z;\varphi)(1+\tau^c(z;\varphi))} - \frac{W'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))}\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1} \\ = & \frac{2\gamma\frac{\varepsilon_\mu(z;\varphi)}{z}}{c(z;\varphi)(1+\tau^c(z;\varphi))} \end{aligned} \tag{2.16}$$

Here, $\varepsilon_\mu(z';\varphi) \geq 0$ such that a rising path of real liabilities z implies that the LHS of equation (2.16) is positive,[25] while the RHS is positive only for $\varepsilon_\mu(z;\varphi) > 0$. Thus, for $z < z^*$, at a candidate stage game equilibrium with $\varepsilon_\mu(z;\varphi) = 0$, the monetary authority has an incentive to deviate by increasing the money supply in order to prevent an excessive accumulation of debt. At the steady state z^*, this incentive persists as can most easily be seen from the fiscal optimality condition (2.13) which prescribes $\varepsilon_\mu(z^*;\varphi) = (1-\frac{\delta}{\beta}) > 0$.

In our economy, the Friedman rule implementing zero nominal interest rates corresponds to a gross rate of money growth of $(1+\mu(z;\varphi^{FR})) = \beta$; due to the

[25]This follows from the strict concavity of the monetary value function $W(\cdot)$ and the fact that $0 > \varepsilon_{c(1+\tau^c)}(z;\varphi) = -\varepsilon_\mu(z;\varphi)$, whereby the last equality is established via total differentiation of the consistency condition (2.11).

non-negativity constraint on nominal interest rates, we have $\mu(z;\varphi) \geq \mu(z;\varphi^{FR})$ for any feasible time consistent policy rule φ. As shown above, $\varepsilon_\mu(z;\varphi) > 0$ for all $0 < z \leq z^*$; hence, generically we have $\mu(z;\varphi) > \mu(z;\varphi^{FR})$, implying distorted nominal interest rates. Therefore, since the nominal interest rate is an opportunity cost on holding money balances, and since carrying nonnegative amounts of currency is inevitable due to the CIA constraint, the adverse impact on welfare is immediate.[26] For this reason, we call any policy rule φ characterized by $\varepsilon_\mu(z;\varphi) > 0$ a rule subject to an *inflation bias*. We summarize our results in:

Proposition 2.1 *For $\delta < \beta$ and $\gamma \in (0,1)$ any (differentiable) Markov-perfect equilibrium involves $\varepsilon_\mu(z;\varphi) > 0$ for all $0 < z \leq z^*$. In other words, there is no non-responsive (differentiable) Markov-perfect equilibrium, and for any time consistent policy rule φ, there is an inflation bias.*

Against the background of this result, it is interesting to investigate how changes in the two authorities' preference parameters impinge on the properties of the equilibrium outcomes. First, consider the effect of a lower fiscal discount factor δ, holding β fixed. The induced decrease in the ratio $\frac{\delta}{\beta}$ implies throughout the state space that $\varepsilon_\mu(z';\varphi)$ must increase, as can be inferred from the fiscal optimality condition (2.13). This means that a more impatient fiscal authority triggers a monetary policy which must be more responsive to variations in the stock of debt. The consequence of this is that $W'(z;\varphi)$ becomes more negative since the associated money expansions are antipicated and accentuate the indirect liability costs of any given amount z of outstanding debt. Revisiting the monetary optimality condition (2.16) at the steady state implemented by the equilibrium policy reveals $\left(\frac{2\gamma}{z^*} + W'(z^*;\varphi)[1 - \varepsilon_\mu(z^*;\varphi)]^{-1}\right) = 0$. With $W'(z;\varphi)$ being globally more negative, the only way this can be achieved is via a lower z^*. This establishes the following result:

Proposition 2.2 *Given β, a more impatient fiscal authority, characterized by a lower δ, triggers a more responsive monetary policy as measured by a higher $\varepsilon_\mu(z;\varphi)$ for all $z > 0$, but the steady state level of debt z^* implemented as the Markov-perfect equilibrium outcome is lower.*

The intuition for this proposition is as follows: A more impatient fiscal policy maker incurs higher deficits which - if an excessive accumulation of debt is to be prevented - must be partially monetized by money expansions. Since the increased fiscal impatience accentuates the monetary margin already for lower levels of debt

[26] To be precise, the welfare losses do not stem from strictly positive nominal interest rates per se; as seen from (2.8), what ultimately matters is the overall distortion $(1+R)(1+\tau^c)$. Rather, they stem from the fact that $\varepsilon_\mu(z;\varphi) > 0$ such that expectational effects imply that nominal interest rates are systematically affected by the amount of real liabilities z.

and since the monetary authority is reluctant to use its instrument, the equilibrium features a more aggressive monetary policy which implements a lower long run level level of debt z^* in order to economize on the extra liability costs of outstanding debt.

Next, consider what happens if γ, the monetary authority's aversion against surprise inflation is increased. Again, $\varepsilon_\mu(z^*;\varphi)$, the degree of monetary responsiveness at the steady state z^*, is pinned down by $\frac{\delta}{\beta}$; since the latter is unchanged, the equilibrium value for $\varepsilon_\mu(z^*;\varphi)$ must be influenced by two effects which neutralize each other: On the one hand, the improved - *but still incomplete* - commitment implied by a higher γ leads to lower absolute values for both $\varepsilon_\mu(z;\varphi)$ and $W'(z;\varphi)$ for any given value z. On the other hand, there is the effect via the steady state value z^* at which the relevant expressions are evaluated. Again, the steady state condition $\left(\frac{2\gamma}{z^*} + W'(z^*;\varphi)[1-\varepsilon_\mu(z^*;\varphi)]^{-1}\right) = 0$ is helpful: Here, a higher γ is compensated for by a higher z^*; however, since an increase in z simultaneously works to make the expression $W'(z;\varphi)[1-\varepsilon_\mu(z;\varphi)]^{-1}$ more negative, a less than proportionate increase in z^* is sufficient. While the intuition underlying this result is very similar to the one for the first parameter change discussed, the second part of the following proposition suggests an interesting institutional interpretation:

Proposition 2.3 *With a more inflation-averse monetary authority, characterized by a higher $\gamma \in (0,1)$, an impatient fiscal policy triggers a less responsive monetary policy as measured by a lower $\varepsilon_\mu(z;\varphi)$, but the steady state level of debt z^* implemented as the Markov-perfect equilibrium outcome is higher.*

This proposition has the remarkable implication that a more "conservative" central bank, identified as a monetary authority which is more averse against the surprise use of its inflation tax instrument, will generally not be more successful in containing the accumulation of public debt. This theoretical finding is also confirmed numerically as evidenced by Figure 2.3 which compares the dynamic evolution of real debt for three alternative economies; the basic parameterization is the same as in the initial numerical example, but the monetary authority's inflation aversion parameter γ varies in the set $\{0.5; 0.7; 0.9\}$. Importantly, the following trade-off arises: Monetary conservatism is a successful commitment device to constrain the monetary accommodation of fiscal profligacy, but at the same time a higher stock of debt is accumulated in equilibrium. What happens is that at any given level of debt z, the recourse to the inflation tax is lower; but since this advantageous commitment effect is (i) incomplete and (ii) understood by the fiscal authority, the latter has an incentive to accumulate more debt. The reason is that the crowding out of consumption via debt will be less pronounced because monetary conservatism helps to economize on the extra liability costs of public debt.

For economic environments where a monetary time consistency problem has bite, the conventional presumption is that monetary conservatism has a positive value. In contrast, the present analysis establishes that the welfare gains during the transition to the steady state must be weighted against the costs of inducing a steady state with higher accumulation of real liabilities. Numerically, it turns out that the transitory gains from monetary conservatism are overcompensated by the long run costs:

Result 2.1 *With an impatient fiscal authority ($\delta < \beta$), the higher the degree $\gamma \in (0,1)$ of the monetary authority's inflation aversion, the lower the lifetime utility $U(z, z; \varphi)$ enjoyed by the representative household.*

This assessment of the welfare implications of monetary conservatism is graphically illustrated in Figure 2.4, which plots the representative household's value functions $U(z, z; \varphi)$ for the same variation of the monetary authority's inflation aversion parameter γ as in the experiment underlying Figure 2.3. Increased monetary conservatism is found to induce negative welfare effects. The welfare effects of a given variation in γ depend on the amount of outstanding liabilities; in particular, for low levels of debt, the relative welfare costs of increased conservatism are larger than for high levels of debt. This is understood from the fact that public liabilities are the source of the monetary ex-post incentive to inflate the economy: A lower degree of inflation aversion goes along with stronger incentives to monetize part of the inherited liabilities. From the rational expectations consistency condition, which links the initial nominal interest rate R_0 to the equilibrium rate of inflation in the first period, this gives rise to higher interest rate distortions. The importance of this effect relative to the long run effects due to convergence to a steady state characterized by lower public indebtedness is increasing in the amount of initial ($t = 0$) liabilities. Hence, as seen in Figure 2.4, the relative disadvantage of monetary conservatism declines when the amount of initial liabilities increases. Nevertheless, the absolute level of welfare attained under increased monetary conservatism is still lower than the one available with a lower degree of inflation aversion. This result underpins the notion that the positive effect of a higher γ, which contains the monetization of any *given* amout of outstanding liabilities z, is dominated by the negative effect that a higher amout of debt is accumulated in equilibrium.[27]

[27]The fact that the monetary time consistency problem can be strategically exploited by the fiscal authority even in case of an explicitly inflation-averse monetary policy maker raises the question of whether there are institutional arrangements that may help to mitigate the adverse welfare consequences. Obviously, in the present context fiscal constraints can play a role as an institutional complement to an otherwise ineffective conservative central bank. Within the framework considered, such constraints should be designed to provide a ceiling to the maximum admissible amount of real debt. Alternatively, establishing a limit on fiscal deficits can help as an auxiliary device to constrain the accumulation of debt resulting from the fiscal authority's impatience. With a binding constraint on deficits, the long run level of real debt would be lower, and the transition to the long run steady state would proceed along a path featuring lower rates of inflation.

2.5 Related literature and concluding remarks

Fiscal discipline is often seen as a requirement for price stability, both in independent economies and monetary unions. In this paper, we have adopted the view that policy makers are unable to commit to future policies. Hence, due to its power to sequentially inflate away the nominal debt of the government sector against the private sector, the monetary authority suffers from a time consistency problem. Against this background, we have analyzed the interaction between monetary and fiscal policy in a deterministic dynamic general equilibrium model. The contributions of this paper are of both conceptual and applied nature. On conceptual grounds, the paper has provided a method to characterize and compute the MPE outcomes in a dynamic general equilibrium economy with large interacting players who cannot commit to future policies but are bound by the requirement that their combined actions must be compatible with a competitive equilibrium of the economy. The paper has then applied this idea to the interaction of monetary and fiscal policy in the presence of nominal government debt. The central insight to be gained from the analytical and numerical results is that an impatient fiscal authority can strategically exploit the time consistency problem inherent in monetary policy making. This finding is reminiscent of what Chari and Kehoe (2004) establish in the context of a monetary union. However, the mechanism involved is different in our context. Whereas Chari and Kehoe build their analysis on a free-rider problem between the fiscal constituencies in a monetary union,[28] our starting point is a politico-economic friction that results in diverging preferences about the accumulation or decumulation of government debt. On the basis of this setup, our analysis proposes a positive theory of government indebtedness and inflation.

In this respect, the paper relates to a number of fiscalist approaches to the determination of the price level. As laid out in the Introduction, the key difference between such fiscal theories of the price level and the traditional monetarist view lies in the role of the government's intertemporal budget constraint, which links the real value of debt to the present value of primary surpluses the fiscal authority will run in the future. In two recent studies, Bassetto (2002, 2005) examines the fiscal theory of the price level from a game-theoretic perspective and addresses the issue of government commitment. Specifically, he pays close attention to the behavior of the economy out of equilibrium. With this approach, he is able to shed light on the nature of the restrictions on fiscal policy due to the intertemporal budget constraint. Taking as given some target policy, Bassetto asks two main questions: (i) Is the fiscal authority actually able to adhere to this targeted policy in all contingencies, i.e. also *off the equilibrium path*? (ii) If not, can the fiscal authority implement

[28]Other papers that address the rationale for fiscal rules on the basis of fiscal externalities in monetary unions include Beetsma and Bovenberg (1997, 1998, 1999), Beetsma and Uhlig (1999) or Dixit and Lambertini (2001, 2003b).

the targeted policy as a *unique equilibrium outcome*? His answer basically is that unconditional rules involving spending levels that exceed the tax revenue in some period are misspecifications, while the fiscal authority can implement any competitive equilibrium as a unique equilibrium. Essentially, this means that the fiscal authority must comply with a budget constraint both on and off the equilibrium path, but has the power to select specific equilibria. Similarly, the present paper establishes that an impatient fiscal authority can reject a non-inflationary candidate equilibrium by refusing to balance the primary budget.

In this paper, we have restricted attention to what happens *on the equilibrium path*. In contrast to Bassetto, we specify objective functions for two separate government authorities and demand that these authorities must be willing to adhere to their policy rule in any subgame. While our approach suffers from the drawback that we are not able to completely characterize what happens off the equilibrium path,[29] we are nevertheless able to provide some important insights. We identify the incentives involved and develop a notion of dominance between the two authorities which is not exogenously assumed, but rather derived as an endogenous result of the primitives of the dynamic game. Specifically, it is shown under which conditions and to what extent fiscal policy can gain leverage over monetary outcomes. So, our approach generates results similar to those of the fiscal theory, but without relying on a reinterpretation of the intertemporal government budget constraint as a mere equilibrium condition, a view that has been subject to much criticism on theoretical grounds.[30]

Having discussed the relationship between the fiscal theory and our approach, it should be stressed that the methodology we use is more in the tradition of the optimal taxation literature. The time inconsistency of optimal plans has first been identified by Kydland and Prescott (1977); subsequently, Barro and Gordon (1983b) have applied this framework to a positive theory of monetary policy making. In a paper closely related to ours, Díaz-Giménez et al. (2006) explore the implications of nominal government debt on optimal monetary policy. Since the contribution by Lucas and Stokey (1983) also fiscal policy has been the topic of further research; important contributions include Chari and Kehoe (1990), Klein and Ríos-Rull (2003) or Klein, Krusell and Ríos-Rull (2003). However, in spite of the institutional arrangements that we observe in most developed economies, when the focus of their analyses is monetary (fiscal) policy, all these papers essentially assume that fiscal (monetary) policy is absent or exogenously given to the model. Against this background, our innovation has been to consider a setting with an inherent time consistency problem

[29] The point is that our model is tacit about what happens if a pair of policy choices is incompatible with a competitive equilibrium. In such situations the crucial question is: How does the adjustment process work to restore equilibrium?

[30] Compare e.g. Kocherlakota and Phelan (1999), Buiter (2002) or Niepelt (2004).

which gives rise to a dynamic policy game where monetary *and* fiscal policies are decided upon by two separate authorities.

So far, the interaction between monetary and fiscal policy in a dynamic framework with optimizing authorities seems to have been neglected in the literature. An exception is the work by Dixit and Lambertini (2003a) who consider monetary-fiscal interactions with a conservative central bank and varying degrees of commitment of the two authorities. Their analysis is cast within a linear-quadratic framework and shows that monetary commitment is negated when fiscal policy is discretionary. This result is similar to our finding that, despite its inflation aversion, the monetary authority is unable to implement a zero-inflation equilibrium when the fiscal authority is impatient. Similar in spirit, Adam and Billi (2005) investigate a sticky price economy where output is inefficiently low due to the market power of firms. Their paper is complementary to the present paper since the setup the authors consider is one where monetary policy controls the nominal interest rate, while fiscal policy decides about the provision of public goods and taxation is lump-sum; moreover, their setup gives rise to a problem of dynamic inconsistency also for fiscal policy, while only monetary policy is subject to a time inconsistency problem in our economy. Adam and Billi analyze the dynamic economy under varying assumptions on the degree of the authorities' commitment capability. Specifically, they propose a conservative central bank as an institutional arrangement that may mitigate the distortions associated with sequential policy making. Importantly, not only does the discipline afforded via monetary conservatism eliminate the distortions due to sequential monetary policy making, but at the same time it also does away with those due to sequential implementation of fiscal policy. In contrast, the present paper establishes that monetary conservatism may fail to achieve these objectives. In detail, it complements the conventional view by illustrating the costs of monetary conservatism resulting from the superior commitment capacity being exploited by a sequential fiscal policy maker who accumulates more public debt. Our approach has facilitated this novel insight because it features a measure of real government liabilities as an endogenous state variable which is strategically manipulated over time.

A number of questions remain open and should be addressed in future research. First, we have already mentioned that our model falls short of a complete game-theoretic specification of the economy. Particularly, not all outcomes off the equilibrium path nor the adjustments from there are well-defined. A relevant scenario of this kind is a debt crisis where households simply refuse to buy government debt at any intertemporal price. Incorporating such a crisis in our model as a zero-probability event or explicitly along the lines of Cole and Kehoe (2000) would be a very interesting, if difficult, extension. Second, our model takes government spending to be exogenous. In the baseline model presented here, we assume a constant path of public spending. However, most projections for advanced economies[31] predict rising levels of government expenditure due to the pressures associated with ageing societies. Hence, it would be a worthwhile exercise to investigate how a deterministic trend in government spending would affect the dynamic game played between monetary and fiscal policy. Finally, by considering only one-period bonds our paper abstracts from the maturity structure of government debt. Indeed, it has been demonstrated how a richer maturity structure can help to overcome the time consistency problem faced by policy makers.[32] In the context of the dynamics of the fiscal theory of the price level, Cochrane (1999) has demonstrated that in an environment, where the inflation tax would otherwise operate as a lump-sum instrument, the introduction of long-term debt has the effect of converting the inflation tax from a lump-sum into a distortionary source of revenue by pushing the inflation generated by tax cuts into the future. The question then is how this result carries over to our setup where there is strategic interaction between a monetary and a fiscal authority.

[31] Compare e.g. OECD (2002).

[32] Compare Lucas and Stokey (1983), Persson, Persson and Svensson (1987) as well as Calvo and Obstfeld (1990).

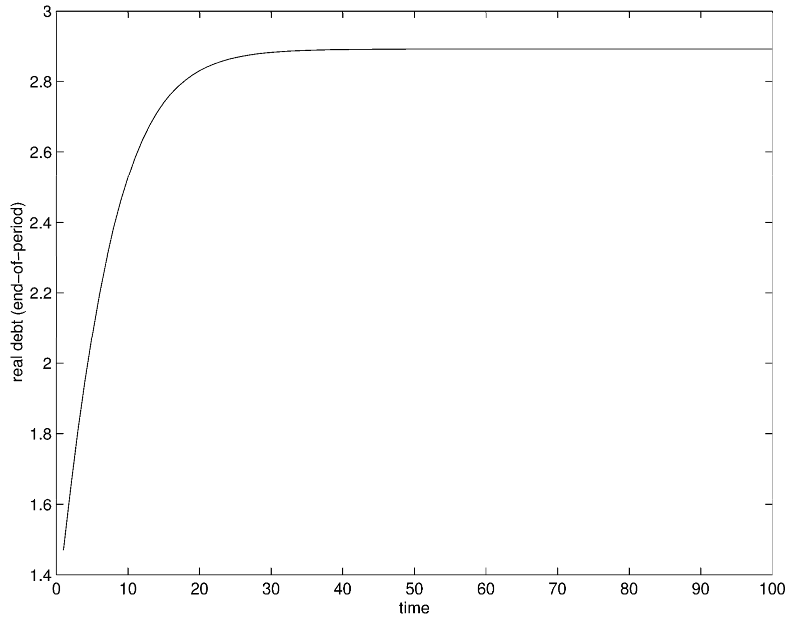

Figure 2.1: Path of real debt in benchmark example

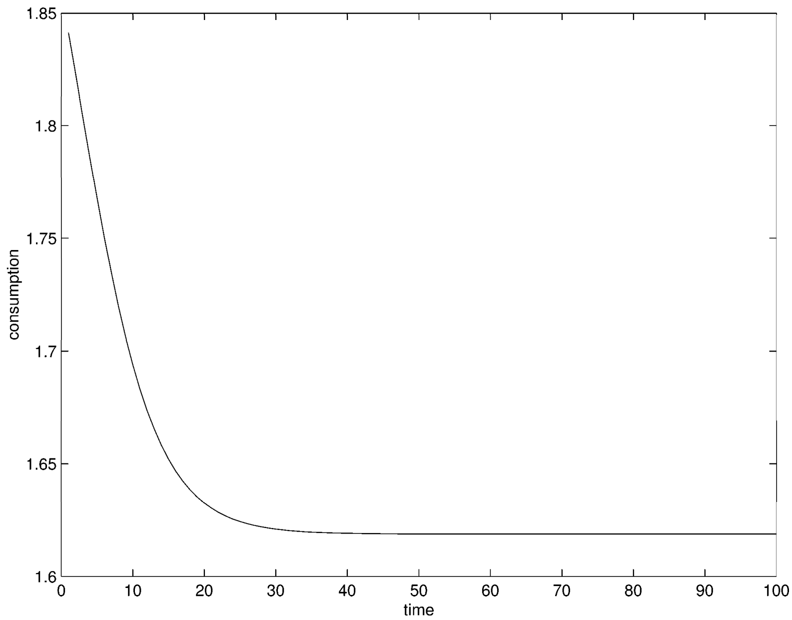

Figure 2.2: Path of consumption in benchmark example

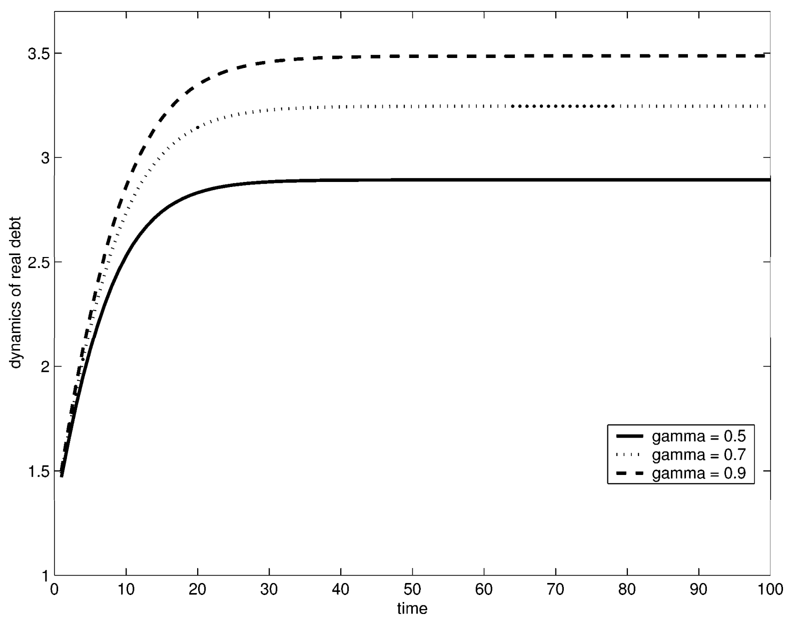

Figure 2.3: Debt dynamics for different degrees of monetary conservatism

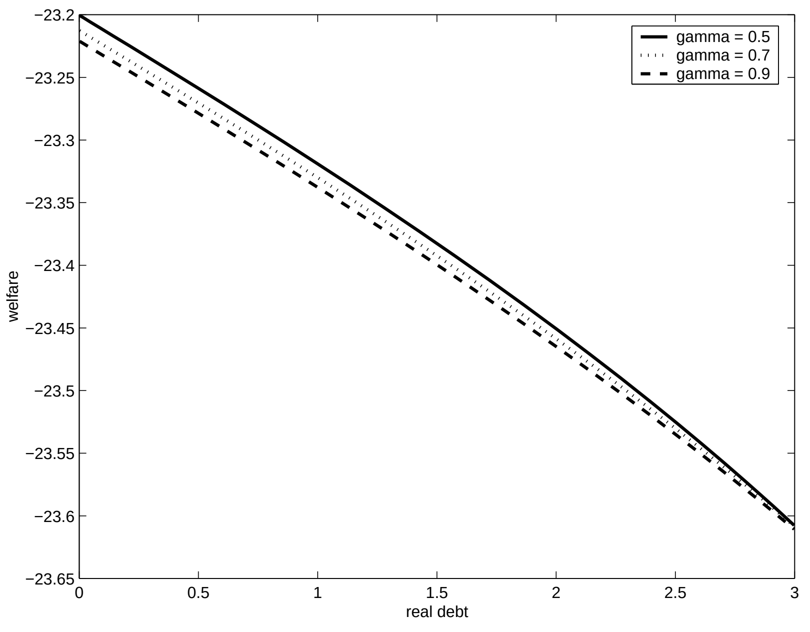

Figure 2.4: Representative household's welfare for different degrees of monetary conservatism

Chapter 3

Inflation, Investment Composition and Total Factor Productivity

3.1 Introduction

The starting point for this paper[1] is the empirical finding of a negative relation between inflation and total factor productivity (TFP), both at business cycle frequency and over longer horizons. Economic interpretations of this correlation can pursue two ways, depending on the direction of causality that is stressed. Indeed, in standard (complete markets) monetary business cycle models featuring an exogenous productivity process and a quantity relation between money, output and prices, it is the case that - ceteris paribus - a negative productivity shock is associated with a higher rate of inflation. Hence, the premise in this class of models is a causal negative effect of TFP on inflation. However, given that TFP is taken to be an exogenous residual, this is an unsatisfactory situation; the reason is that we are left with a "measure of our ignorance" (Abramovitz, 1956) in order to explain economic processes of first priority. This paper takes a different route. While we do not question the merits of the aforementioned class of models for the purpose of studying macroeconomic dynamics, we reverse the underlying notion of causality between inflation and TFP by proposing that the latter variable can be seen as a function of the former one. This implies that TFP is no longer an exogenous residual, but becomes an endogenous variable which is determined in the general equilibrium of the economy. Empirically, the findings emerging from US aggregate time series data at quarterly and yearly frequency provide robust evidence in favor of this hypothesis. In particular, higher inflation is significantly found to negatively affect TFP(-growth), whereby the exogeneity of inflation cannot be rejected; thus, there is evidence that the negative relation between inflation and TFP is indeed due to a causal effect from inflation to TFP.

[1] This chapter draws on joint work with Michael Evers and Marc Schiffbauer.

Against this background, the present paper concentrates on the *supply-side effect of monetary policy on TFP*. Specifically, we argue that it is not appropriate to treat shocks to monetary policy and aggregate technology as orthogonal. The transmission mechanism that we put forward in order to rationalize the negative relationship between inflation and TFP is tied to the composition and effectiveness (in a sense to be defined below) of aggregate investment. To formalize our argument, we develop a model economy whose underlying structure is based on the common point of departure of both business cycle and growth theory: the neoclassical growth model. This basic model is modified along three dimensions. *First*, it features a cash-in-advance (CIA) constraint and incorporates the assumption of limited asset market participation; this allows for liquidity effects and hence for non-neutrality of monetary policy even in an environment with flexible prices. *Second*, the model does not involve a comprehensive aggregate production function, but starts from the presumption that investment can be channelled into two distinct technologies: a safe, but return-dominated ("basic") technology and a superior ("advanced") technology which yields higher expected returns, but is subject to idiosyncratic liquidity shocks. Agents operating the latter technology can insure themselves against such idiosyncratic risk by means of holding a precautionary stock of readily marketable assets. However, due to an entrepreneurial moral hazard problem, which is the *third* key building block of the model, the scope for insurance is limited. The consequence of this friction is that financial markets are incomplete in that scarce liquidity cannot be optimally provided to the productive sector. In particular, given that insurance against liquidity shocks is costly, variations in the costs of insurance trigger shifts in the composition of aggregate investment which are associated with changes in TFP. In the model we put forward, these costs coincide with the nominal interest rate. Specifically, in addition to its role with respect to the opportunity costs of consumption in a simple monetary cash-in-advance model, the nominal interest rate works as a liquidity premium and thus constitutes an additional cost of production by means of the advanced technology relative to the basic one. Hence, the model postulates a novel aspect of monetary transmission in that movements in the nominal interest rate are associated with changes in the composition of investment in the two available technologies.

In view of above arguments, it is evident that the present paper borrows from both business cycle and growth theory: It considers monetary and technological shocks as well as their interaction with a specific financial markets friction, but at the same time endogenizes the aggregate productivity process via an endogenous technology choice which is catalyzed by this friction.[2] Here, we focus on the

[2]For a similar approach, compare the recent paper by Aghion et al. (2006) who paraphrase the situation as follows: *"The modern theory of business cycles gives a central position to productivity shocks and the role of financial markets in the propagation of these shocks; but it takes the entire*

corresponding cyclical and steady state implications, but abstract from the pertinent endogenous growth effects.[3] Instead, we elaborate on the source of market incompleteness which limits financial markets' capability to provide liquidity to the corporate sector. In particular, we detail a set of predictions regarding the interaction of variations in the liquidity premium with certain supply-side characteristics at the industry level; moreover, following Holmström and Tirole (1998), we provide an explicit framework which illustrates how these interaction effects can be *endogenously* derived from a particular entrepreneurial agency problem. Hence, constrained-efficient contracting in the face of incomplete insurance against idiosyncratic liquidity shocks delivers a number of implications concerning the reaction of the productive sector to monetary policy shocks and the way in which industry-level characteristics affect specific industries' sensitivity to such shocks. Specifically, following movements in the nominal interest rate, the response of industries which are more profitable and more exposed to advanced technologies is predicted to be more pronounced.

In order to assess the quantitative and empirical relevance of the proposed transmission mechanism, we adopt a twofold strategy: *One the one hand*, we interpret our model as a literal business cycle model and calibrate it to US data. The calibrated benchmark economy is then compared to alternative economies whose basic structure is identical, but where either monetary shocks are absent or the steady state rate of inflation is varied. Comparing the respective model-generated moments, we conclude (i) that, by generating an investment-composition driven variation in TFP, monetary policy shocks can account for a significant proportion of macroeconomic fluctuations, and (ii) that systematic changes in the level of inflation induce sizeable changes in the level of TFP. *On the other hand*, in order to substantiate the empirical relevance of our basic hypothesis that nominal fluctuations affect the composition of aggregate investment, we complement our empirical findings pertaining to aggregate US data by an analysis of disaggregate industry-level and firm-level panel data. In doing so, we provide evidence consistent with (i) the implications of constrained-efficient contracting with respect to the postulated agency problem, as well as (ii) the notion that corporate liquidity holdings are used as a precautionary buffer stock to hedge investment into advanced technologies and that the scope of such insurance is negatively affected by the level of inflation. We view these findings as strongly supportive of our theory.

The rest of the paper is organized as follows. The next section briefly synthesizes the established empirical findings on the effects of inflation on economic performance

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productivity process as exogenous. The modern theory of growth, on the other hand, gives a central position to endogenous productivity growth and the role of financial markets in the growth process; but it focuses on trends, largely ignoring shocks and cycles."

[3] An endogenous growth perspective is adopted in Evers, Niemann and Schiffbauer (2007).

and reviews the related literature. Then, Section 3.3 provides detailed evidence on the relationship between inflation and TFP in the US economy. Against this background, Section 3.4 proposes a business cycle model as the theoretical framework for formulating our main hypotheses. Section 3.5 examines the quantitative properties of the calibrated benchmark economy as well as those of alternative model economies. In Section 3.6, we undertake an empirical analysis of (panel) data at different levels of aggregation in order to underpin our proposition that the composition of aggregate investment is crucially affected by the firm-level conditions for insurance against liquidity risk. A final section concludes, while some auxiliary information, including the explicit derivation of the solution to the financial contracting problem, is relegated to the Appendix.

3.2 Related literature

Empirical literature: In line with the present paper's focus, we organize our reading of the relevant empirical work in two steps: First, we draw on the literature to provide evidence on the relationship between inflation and economic performance, also shedding light on the respective effects on factor accumulation and aggregate productivity. Second, we resort to evidence from disaggregate firm-level data which provides valuable background information with respect to the transmission mechanism proposed in this paper.

Applying cross-sectional and panel growth regressions for yearly data, Fischer (1993) finds a negative correlation between inflation and economic growth.[4] The author investigates the causal mechanism behind this correlation in several ways. First, by considering sample variations across periods predominated by demand (1960-1972) or supply (1973-1988) shocks, he examines the potential endogeneity of inflation. He starts from the presumption that adverse supply shocks are the main source of the potential endogeneity of inflation (while an adverse supply shock is inflationary, an adverse demand shock would be deflationary). However, he finds that the correlation between inflation and economic growth remains unchanged across the relevant subsamples and is therefore led to the conclusion that inflation is exogenous with respect to growth. Second, by means of a growth accounting exercise, Fischer decomposes GDP-growth into its components and detects a robust negative relation between inflation on the one hand and the growth rate of capital, but also of TFP

[4] Other contributions include De Gregorio (1992, 1993), Barro (1996), Bruno and Easterly (1998) and Easterly (2005). Generally, three potential mechanisms are put forward to rationalize the negative relationship: (i) the adverse effects on economic performance of distortions in the informational content of the price level due to aggregate uncertainty; (ii) the reduction in capital accumulation stemming from a temporary hold up of investment decisions in the presence of aggregate uncertainty; (iii) the inflation tax on returns from capital and R&D investment if investors must hold cash-in-advance.

on the other hand. These two results have striking implications: They indicate that the negative correlation between inflation and GDP-growth cannot be (exclusively) due to adverse technology shocks. And they demonstrate that, even after controlling for factor accumulation and employment, the negative effect of inflation on growth persists; that is, there must be some inflation-driven mechanism which records in terms of decreased aggregate productivity.

The model we develop in Section 3.4 proposes that inflation, by making the provision of liquidity more costly, affects investment in a way that shifts activity from superior to return-dominated, but safer technologies. A natural way to operationalize arguments concerning the composition of aggregate investment is to use data on R&D expenditures to proxy investment in superior technologies. Wälde and Woitek (2004) report the overall *level* of R&D expenditure to be procyclical. Conversely, Aghion et al. (2006) focus on the cyclical variation of R&D as a *share* of total investment. On the basis of dynamic panel estimations, they find that the R&D share and aggregate investment have markedly different business cycle properties, which hints at the potential importance of a decomposition of aggregate investment in order to account for business cycle phenomena.

At the disaggregate level, our study seeks to empirically assess how nominal fluctuations impact on firms' investment decisions when financial markets are incomplete.[5] The basic take of our theory is that the availability of corporate liquidity is a crucial determinant for firm-level investment. To get some guidance on the potential power of this mechanism, we resort to the findings in Opler et al. (1999) who examine the determinants and implications of holdings of cash and marketable securities by publicly traded non-financial US firms.[6] The authors establish that firms with better outside financing opportunities tend to hold a lower fraction of their total assets in the form liquid assets, and that firms with strong growth opportunities and riskier cash flows hold relatively high ratios of cash to total non-cash assets.[7] Therefore, there is evidence that firms retain a relatively high fraction of their earnings as liquid reserves and that these reserves are generally not used for capital investment, but rather tend to be depleted by operating losses, i.e. corporate liquidity is held as a hedge against production risk. As to the quantitative importance of corporate cash holdings, the authors report the mean over the firms in their sample of the ratio of cash to net assets at 18%, while the median amounts to 6%. Thus, corporate liquidity holdings are likely to constitute

[5]For a review of the literature on corporate investment see Hubbard (1999).

[6]Most theoretical and empirical studies of corporate cash holdings start from the presumption that external finance is costly and that firms hold liquid assets in order to survive bad times and to have funds readily available if an investment opportunity arises. The benefits of corporate liquidity must then be balanced against its costs which arises as a consequence of a liquidity premium.

[7]We interpret these latter features - high growth potential and risky cash flows - as the identifying characteristics of what we label "advanced" technology.

a quantitatively relevant category for the transmission of macroeconomic shocks and in particular of fluctuations in nominal variables like the rate of inflation or the nominal interest rate. In the present paper we will elaborate on this hypothesis.

Theoretical literature: Characterizing a theoretical framework for an empirically plausible monetary transmission mechanism is the subject of a large set of macroeconomic models set up either in flexible or sticky price environments.[8] Our own model presents a flexible price economy generating monetary non-neutrality via a CIA constraint and the additional assumption of limited asset market participation;[9] an important empirical phenomenon replicated in models characterized by limited asset market participation is the *liquidity effect*, i.e. a fall in nominal interest rates following an (unexpected) monetary expansion. We augment a simple monetary model along these lines by a financial market friction which is motivated by an entrepreneurial moral hazard problem and gives rise to a well-defined corporate demand for liquidity. Starting from the contribution by Bernanke and Gertler (1989), there is an extensive literature dealing with the interaction of financial market frictions and the monetary transmission process. In this context, the dynamics of corporate investment and the heterogeneity of firms' responses to monetary policy shocks have received particular attention.[10] Here, we make no attempt to systematically review this literature; instead, we concentrate on contributions developing some of the aspects which feature prominently in our own model.

The key propagation mechanism we invoke to explain the negative relation between inflation and TFP is an investment composition effect in the presence of incomplete financial markets. In a real economy, Aghion et al. (2006) use a similar decomposition of aggregate investment in order to examine how credit constraints affect the cyclical behavior of productivity-enhancing investment. To that end, the authors develop a growth model where investment can be sunk into either a short-term project or a long-term project which enhances future productivity. Importantly then, aggregate productivity has both an exogenous and an endogenous component. The exogenous component is specified as in a conventional real business cycle model, whereas the endogenous component is driven by the mass of long-term projects that have been successfully completed in the past. Similar to our "advanced" technology, survival of long-term projects is uncertain because they are subject to idiosyncratic liquidity shocks which - for reasons left unspecified - can only be imperfectly insured.

[8] Compare e.g. Christiano, Eichenbaum and Evans (1997, 2005) and the references therein.

[9] See Cooley and Hansen (1989, 1998) for monetary business cycle studies based on CIA constraints and Lucas (1990), Fuerst (1992) or Christiano and Eichenbaum (1992, 1995) for developments of the limited participation framework.

[10] A selection of general contributions includes Bernanke and Gertler (1995), Bernanke, Gertler and Gilchrist (1996, 1999) and Carlstrom and Fuerst (1997); Cooley and Quadrini (2006), Fisher (1999) and Gertler and Gilchrist (1994) are concerned with heterogenous firm dynamics.

In this setup, the assumed stochastic structure of aggregate shocks alters the amount of scarce resources available to insure idiosyncratic liquidity risk in a procyclical fashion. As a consequence, the survival probability of any given productivity-enhancing project is procyclical which generates an investment composition effect giving rise to further procyclical momentum in the process for productivity growth and the business cycle. Another paper concerned with the composition of aggregate investment when financial markets are incomplete is Angeletos (2007). He studies the effects of idiosyncratic investment risk on the aggregate level and the allocation of savings within the framework of a non-monetary neoclassical growth model. One particular model variant considers the general equilibrium properties of an economy where there is the choice of investing into either privately-held risky projects or public equity, wherby the latter allows to pool idiosyncratic risks. One of the model's implications then is that, quite similar to what will happen in the model economy developed in section 3.4, incomplete markets reduce TFP by shifting resources away from the more risky, but also more productive private equity investment.

Both Aghion et al. (2006) and Angeletos (2007) are concerned with real general equilibrium economies; hence, nominal aspects do not play any role. Moreover, in contrast to our own model, the implications for the economy's cyclical dynamics critically hinge on the assumption that uninsured idiosyncratic investment risk evolves in a countercyclical fashion. The present paper addresses both these issues at the same time. We set up a monetary business cycle model to show how the effects of financial market frictions on the composition of physical investment are shaped by the relative price for insuring superior investment activities, the *nominal interest rate*. This nominal rate is affected by monetary fluctuations and is determined in the model's general equilibrium such as to equilibriate the supply of short-term credit by the household sector with the demand for short-term credit from in the productive sector. Finally, in order to better understand the determinants of the interaction between the nominal interest rate and the scope for liquidity provision, we explicitly specify the source of market incompleteness which gives rise to uninsured idiosyncratic risk.[11] This allows us to derive a number of theoretical predictions which can be empirically examined.

[11] Specifically, we embed the contracting problem discussed in Holmström and Tirole (1998) into our business cycle model. Kato (2006) adopts a similar approach, but in a real model. Meh and Quadrini (2006) consider a model with endogenous market incompleteness with respect to individual investment risk.

3.3 Empirical evidence on the relationship between inflation and aggregate productivity

In this section, we use US time series data and adopt an instrumental variable approach to (i) document how inflation and aggregate productivity are related at business cycle frequency and to (ii) establish that the causal effect of inflation on TFP-growth is transmitted via corporate portfolio choices. That is, we complement the work of Fischer (1993) by employing alternative econometric methods and by examining the transmission channel in more detail. We exploit both quarterly and yearly data since it is not a priori clear whether the effect of nominal fluctuations on TFP fully materializes within a quarter.

As a starting point, we examine the interactions between TFP-growth and inflation at the aggregate level. We employ the first difference of TFP rather than its level since our methodology requires the inclusion of stationary variables.[12] The TFP series is constructed as the residual from the aggregate production function implied by the calibrated one-sector neoclassical growth model to be set out in Section 3.4.[13] Inflation is derived as the first difference of the consumer price index.[14] Moreover, we include GDP-growth and the private investment share relative to GDP as additional endogenous variables. The rationale behind this is that in standard monetary business cycle theories, the effect of inflation on real economic activity (GDP-growth) is due to the adverse impact on aggregate investment of the inflation tax or increased aggregate uncertainty associated with higher rates of inflation.[15]

Table 3.1 reports the results of an unrestricted VAR for quarterly and yearly frequencies as well as the corresponding Granger causality tests. The information criteria suggest the inclusion of a lag length of one in both cases;[16] hence, the Granger causality test reduces to a simple exclusion test of the first lag of the corresponding variable. The information contained in Table 3.1 reveals that inflation reduces TFP-growth in the subsequent period at a quarterly as well as a yearly frequency. This effect is significant on a 5% and 1% level, respectively, and works independently

[12] Indeed, we cannot reject the null hypothesis of non-stationarity (p-value of 0.623) if we apply an augmented Dickey-Fuller test including a trend and two lags for US quarterly TFP data (167 observations).

[13] At yearly frequency, the correlation between the growth rates of our calibrated TFP-series and of the relevant series published by the Bureau of Labor Statistics (BLS) is 0.89; quarterly series are not available from the BLS. For further details, see Appendix C.3.

[14] The base year is 1995. We also employ the GDP deflator; however, we exclusively report the estimates based on consumer prices since the results are very similar in both cases.

[15] See Cooley and Hansen (1989), Chari, Jones and Manuelli (1995), Jones and Manuelli (1990), Ramey and Ramey (1995) or Stockman (1981) for a discussion of such theories.

[16] We stress that the negative (joint) effect of the lags of inflation on TFP-growth is robust to the inclusion of additional lags of the endogenous variables (1-4) at both frequencies. The additional tables are available from the authors upon request.

from the adjustment of the private investment share and GDP-growth. In addition, we find that inflation Granger causes private investment at neither frequency. We infer that, in our sample, the transmission channel of inflation does not rest on private factor accumulation. This result underpins our hypothesis that inflation affects the composition rather than the overall level of private investment.[17] Finally, inspection of reverse causality from TFP-growth towards inflation shows that TFP-growth reduces inflation in the subsequent period at a yearly (significant at a 5% level), but not at quarterly frequency.

These results confirm a negative relation between inflation and TFP-growth at business cycle frequencies. The specific mechanism we put forward in this paper implies that an increase in inflation reduces corporate liquidity holdings which are used as insurance against the risk associated with physical investment relying on advanced technologies. The reduced liquidity holdings, in turn, induce a shift in the composition of investment and hence aggregate changes in TFP. A (non-structural) representation of this mechanism is given by the following system of equations:

$$\Delta\mathcal{T}_t = \alpha^{\mathcal{T}} + \beta^{\mathcal{T}} C_t + X_i'\gamma^{\mathcal{T}} + \epsilon_t^{\mathcal{T}} \quad (3.1a)$$

$$C_t = \alpha^C + \beta^C D_t + X_i'\gamma^C + \epsilon_t^C \quad (3.1b)$$

$$D_t = \alpha^D + \beta^D \pi_t + X_i'\gamma^D + \epsilon_t^D, \quad (3.1c)$$

where $\Delta\mathcal{T}$ is TFP-growth, C is investment composition, D are aggregate corporate liquidity holdings, π is inflation and X is a vector of covariates which affect all variables. In the following, we want to test the macroeconomic mechanism underlying system (3.1). Therefore, we exploit firm-level US data from the Compustat database and average across firms to obtain the relevant aggregate measures. Following Opler et al. (1999), we approximate investment composition by corporate investments in R&D and corporate liquidity holdings by the amount of cash and marketable securities, both relative to total assets. Moreover, we include average operating income, total assets and the amount of long term debt as additional control variables. To deal with an endogeneity problem of average R&D ratios and corporate liquidity holdings with respect to TFP-growth in the sense of $E(C_t \mid \epsilon_t^{\mathcal{T}}) \neq 0$, $E(D_t \mid \epsilon_t^C) \neq 0$, we apply an instrumental variable approach. Specifically, in view of potential contemporaneous feedback effects from TFP-growth to inflation, we assume $E(\pi_{t-1} \mid \epsilon_t^{\mathcal{T}}) = 0$ and employ lagged inflation as an instrument. In fact, the pattern of estimated coefficients from the unrestricted VAR suggests that the first lag of inflation is exogenous to TFP-growth since it Granger causes TFP-growth, while the lagged dependent variable of TFP-growth itself is not significant. If, in addition, the lag of inflation is correlated with average R&D ratios and corporate liquidity holdings (which we illustrate below), it is a valid instrument for these endogenous

[17] Similarly, Ramey and Ramey (1995) and Aghion et al. (2006) call the effect of macroeconomic uncertainty on aggregate investment into question.

measures in equations (3.1a) and (3.1b). Furthermore, we consider the nominal interest rate ($\tilde{R}$) as an alternative measure of nominal fluctuations and apply its first lag as an additional instrument for the endogenous measures in these equations.[18] This allows us to test for the validity of our instruments by employing a Hansen test of overidentifying restrictions. Consequently, we use the first lags of inflation and the nominal interest rate as exogenous instrumental variables to estimate via the general method of moments (GMM) the causal effect of investment composition and average corporate liquidity holdings on TFP-growth. The Hansen test statistic indicates a well-specified econometric model in all reported estimations; furthermore, we always include a lagged dependent variable and incorporate heteroscedasticity-robust standard errors in all estimations. Summing up, we separately estimate the equations:

$$\Delta\mathcal{T}_t = \alpha_C^{\mathcal{T}} + \beta_C^{\mathcal{T}} C_t + X_i'\gamma_C^{\mathcal{T}} + \epsilon_{C,t}^{\mathcal{T}} \quad (3.2a)$$

$$\Delta\mathcal{T}_t = \alpha_D^{\mathcal{T}} + \beta_D^{\mathcal{T}} D_t + X_i'\gamma_D^{\mathcal{T}} + \epsilon_{D,t}^{\mathcal{T}}, \quad (3.2b)$$

whereby we treat C and D as endogenous and model them respectively as:

$$C_t = \alpha_C^C + \beta_1^C \pi_{t-1} + \beta_2^C \tilde{R}_{t-1} + X_i'\gamma_C^C + \epsilon_{C,t}^C \quad (3.3a)$$

$$D_t = \alpha_D^D + \beta_1^D \pi_{t-1} + \beta_2^D \tilde{R}_{t-1} + X_i'\gamma_D^D + \epsilon_{D,t}^D \quad (3.3b)$$

The results for US yearly data are reported in Table 3.2. Columns one to four are concerned with equations (3.2a) and (3.3a). The first column displays a positive correlation between the average R&D investment ratio and TFP-growth. The corresponding coefficient is significant on a 1% level. This positive correlation is independent of changes in average firm size, average operating income across firms, average value of corporate long-term debt and aggregate private and government investment shares. Moreover, the Arellano-Bond (1991) test for autocorrelation indicates the absence of first and second order serial correlation in the error terms. In the next two columns, we instrument advanced (R&D) investments by the first lags of inflation and the nominal interest rate, whereby column two does not employ the set of exogenous controls. In both cases, the results reveal a positive causal effect of advanced investment on TFP-growth which is significant on a 1% level. In addition, the Hansen test shows that the first lags of inflation and the nominal interest rate are valid instruments. Finally, we display the (modified) first stage regression in column four, whereby we excluded the nominal interest rate.[19] The first stage regression indicates a negative impact of the first lag of inflation on advanced investments. The corresponding coefficient is significant on a 1% level. In columns five to eight,

[18]The nominal interest rate is represented by the yield on corporate bonds (Moody's Seasoned Aaa Corporate Bond Yield) because the latter is the closest proxy for firms' cost of external finance.

[19]For unfiltered data, the correlation coefficient between CPI inflation and the nominal interest rate (Moody's Seasoned Aaa Corporate Bond Yield) is 0.42 (0.55) at yearly (quarterly) frequency.

we repeat the same exercise for equations (3.2b) and (3.3b), now instrumenting for our second endogenous transmission variable. First, we detect a positive significant contemporaneous correlation between the average corporate liquidity holdings and TFP-growth. The subsequent IV-estimations reveal that causation is indeed running from average corporate liquidity holdings to TFP-growth. The Hansen test indicates the validity of our instruments in both specifications. Finally, the (modified) first stage regression reports a strong negative impact of lagged inflation on average corporate liquidity holdings which is significant on a 1% level. Summing up, on the basis of annual US time series we find support for our model hypothesis which proposes that inflation and nominal interest rates reduce TFP-growth in the short-run by affecting average corporate liquidity holdings and the composition of firm-level physical investment portfolios.

Table 3.3 is concerned with the same questions, but for quarterly frequency. Due to the higher frequency, we now use the first two lags of inflation and the nominal interest rate as instrumental variables. We find a positive correlation between quarterly average R&D ratios and TFP-growth; as evidenced by columns two and three, applying an IV-approach reveals that causation is running from advanced (R&D) investments to TFP-growth. The first lag of inflation features a negative correlation with the average R&D ratio, which is significant on a 1% level. The results for firms' average quarterly liquidity holdings are less clear-cut. We do not detect a significant positive correlation between this endogenous measure and TFP-growth at a quarterly frequency. Accordingly, at quarterly frequency the IV-approach does not confirm a significant impact of average corporate liquidity on TFP-growth even though the former is negatively influenced by lagged inflation. Overall, the results based on quarterly data appear less robust than the previous ones, which suggests that firms' adjustment in terms of their liquidity holdings or investment portfolios to changes in the level of inflation might not be swift enough to record at quarterly frequency.

To sum up, for US data we find a robust negative empirical relation between inflation and TFP-growth which is independent of changes in the private investment share or GDP-growth. A Granger causality test indicates that causality is running from inflation to TFP-growth. These two empirical observations challenge the presumption of conventional monetary business cycle theories which take the aggregate productivity process as exogenous or stipulate that real effects of inflation are transmitted via changes in the aggregate quantity of investments. The results of the IV-approach suggest that, on average, the aggregate negative effect of inflation on TFP is due to firm-level variations in liquidity holdings and investment composition.

3.4 The model

In view of above empirical findings, we now propose a one-sector model of a monetary economy as a tractable structure formalizing the economic intuition underlying our proposed transmission mechanism. As hinted in the Introduction, the model's key ingredients are (i) limited asset market participation, (ii) endogenous technology choice, and (iii) incomplete financial markets. The economy is populated by two sets of agents, households and entrepreneurs, each of unit mass. The production sector is characterized by two distinct intermediate input goods, labelled "basic" and "advanced" corresponding to the characteristics of the two constant-returns-to-scale technologies which are used to produce them,[20] and by a simple aggregation technology that combines the two intermediate goods to the final market good. Each entrepreneur runs an individual firm producing *both* intermediate input goods, though in distinct projects utilizing the respective technology. The final market good is produced by anonymous firms in a perfectly competitive market environment. In addition, there is a market for financial intermediation which is also assumed to be perfectly competitive. Finally, there is a government ("monetary authority") which implements macroeconomic policies. These policies, together with a set of exogenous shocks, expose the economy to aggregate uncertainty.

The timing structure underlying our model is as follows. Time is discrete, and within each period t, there are three points in time: one at the beginning of the period, denoted t^-, one at an interim stage when the vector s_t of aggregate shocks materializes and information about them is revealed, and finally one at the end of the period, denoted t^+. The aggregate shocks in our model are productivity shocks $\mathcal{A}_t$, $\mathcal{V}_t$ to the two intermediate technologies as well as a shock $\mathcal{J}_t$ to government policy (to be specified later); hence, we have $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$. Apart from these aggregate shocks, there are purely idiosyncratic liquidity shocks ξ_t^i to the single advanced technology project run by an individual entrepreneur. We now turn to a detailed description of the environment in which the economy's agents interact and define their decision problems. The exposition of the solution to the agents' problems as well as of the competitive equilibrium are relegated to the Appendix C.1; the most important equilibrium implications are discussed in in Section 3.4.6.

3.4.1 Households

Households enter a given period t with claims to two distinct capital stocks (k_t, z_t) accumulated from the past together with a nominal wealth position M_t. At time t^-, households divide their nominal wealth into resources Q_t disposable for consumption later in the period and deposits $M_t - Q_t$ with a financial intermediary which earn

[20] As a general rule, variables pertaining to the basic input good are indicated by the variable/superscript k, while z is the relevant indicator for the advanced input good.

a net interest rate $(\tilde{R}_t - 1)$.[21] After aggregate shocks have materialized, households rent out their technology-specific physical capital to the entrepreneurs who run the projects producing the basic and advanced input good, respectively. Similarly, they supply labor $h_t^{k,H}$ to basic and $h_t^{z,H}$ to advanced projects, resulting in an aggregate labor supply of $h_t^H = h_t^{k,H} + h_t^{z,H}$, whereby households are indifferent as to where their labor is employed.[22] As an equilibrium consequence, households will receive the same nominal wage $W_t^{k,H} = W_t^{z,H} = W_t^H$ in both projects. At time t^+, households receive the returns from labor and capital and make consumption and investment decisions. However, there is a cash constraint on the goods market with the consequence that a household's current expenditure for consumption c_t^H and physical investment x_t must be covered by the resources Q_t earmarked for consumption plus a fraction θ of its current wage earnings. The household has preferences over sequences of consumption and labor supply; hence, the household problem is to maximize lifetime utility:

$$E_{0^-} \sum_{t=0}^{\infty} \beta^t u(c_t^H, h_t^H) \tag{3.4a}$$

subject to the cash constraint:

$$Q_t + \theta W_t^H h_t^H \geq P_t[c_t^H + x_t], \tag{3.4b}$$

an equation describing the evolution of nominal assets:

$$\begin{aligned} M_{t+1} &= Q_t + \theta W_t^H h_t^H - P_t[c_t^H + x_t] + \tilde{R}_t[M_t - Q_t + \mathcal{J}_t] \\ &+ R_t^k k_t + R_t^z z_t + (1-\theta) W_t^H h_t^H + \Upsilon_t, \end{aligned} \tag{3.4c}$$

where $\mathcal{J}_t$ are cash injections into the financial market on behalf of the government and Υ_t are nominal resources redistributed in a lump-sum fashion among the consumers at the end of the period; moreover, there is a law of motion for aggregate capital $K_t = k_t + z_t$, which accounts for depreciation and technology-specific adjustment costs $\Phi(\cdot)$:

$$x_t = (k_{t+1} + z_{t+1}) - (1-\delta)(k_t + z_t) + \Phi(k_t, k_{t+1}) + \Phi(z_t, z_{t+1}) \tag{3.4d}$$

3.4.2 Entrepreneurs

Apart from households, there is a unit mass of risk neutral entrepreneurs, each one capable of running a single firm which produces the two distinct intermediary input goods. Any such entrepreneurial firm has access to a neoclassical production plan

[21] This timing convention is standard in monetary models which feature a limited participation assumption on the household side; compare e.g. Lucas (1990).

[22] Where necessary, variables pertaining to the household sector will be denoted with a superscript H; similarly, the superscript E is used to indicate variables pertaining to entrepreneurs.

utilizing the basic technology as well as to a single advanced technology project. At the beginning of each period, a mass $(1-\eta)$ of new-born entrepreneurs enters the economy without any initial wealth and replaces an equal measure of retiring entrepreneurs. The remaining measure η of incumbent entrepreneurs stays active. An individual entrepreneur arrives in period t with an amount A_t^i of nominal wealth. Then, if she receives a random exit signal, she waits until the end of the period to simply consume her accumulated wealth such that $A_t^i = P_t c_t^{E,i}$. In contrast, new entrants and entrepreneurs who have not received the exit signal have no consumption motive; rather, each active entrepreneur inelastically supplies her (unit) labor endowment $h_t^E = h_t^{k,E} + h_t^{z,E} = 1$ and thus augments her nominal wealth A_t^i by her current wage earnings W_t^E. As for households, only a fraction θ of these wage earnings is immediately disposable such that an individual entrepreneur's effective wealth position is $E_t^i = A_t^i + \theta W_t^E$; E_t^i constitutes the entrepreneur's necessary private equity stake when she applies for funding of her advanced project with a financial intermediary.

3.4.2.1 Intermediate input goods

Each of the two intermediate input goods is produced in an environment of perfect competition. Both input goods require capital as well as labor for production, but they are characterized by different technologies. On the one hand, there is a safe, but return-dominated ("basic") technology; the other ("advanced") technology yields a higher potential return, but is subject to idiosyncratic liquidity shocks. The scope for insuring an individual advanced project against this idiosyncratic liquidity risk is endogenously determined via a (constrained-efficient) financial contract. The need for this insurance arises as a consequence of an entrepreneurial moral hazard problem which prevents the efficient refinancing of projects and calls for the commitment of liquidity at the ex ante, rather than the ex post stage. A key distinction between the two technologies is the relevance of entrepreneurial moral hazard for the successful completion of production processes: In particular, we assume the basic technology to be free from the moral hazard problem such that the standard theory of corporate finance applies here; conversely, production by means of the advanced technology is subject to ex post entrepreneurial moral hazard. Another friction that is relevant for both tehnologies is an advance payment requirement, which necessitates borrowing working capital in order to pay wages; specifically, the parameter $\theta \in [0,1]$ represents the fraction of the wage bill to be financed in advance.

Basic technology: Employment of labor and capital inputs (l_t^k, k_t) for the basic technology is chosen such as to maximize time t^+ profits, whereby the vector of prices $(P_t^k, W_t^k, R_t^k, \tilde{R}_t)$ is taken as given. The basic technology producing intermediate goods is assumed to be homogenous of degree one and features labor augmenting technological progress at the exogenous rate γ. For simplicity, we employ the Cobb-Douglas form:

$$\varphi(k_t, l_t^k) = (k_t)^{\alpha^k} \left((1+\gamma)^t l_t^k\right)^{1-\alpha^k}$$

Similarly, a Cobb-Douglas aggregator converts household and entrepreneurial labor inputs into their effective composite, and agent-specific wages aggregate to a composite wage rate:

$$l_t^k = \frac{(h_t^{k,H})^{\Omega}(h_t^{k,E})^{(1-\Omega)}}{(\Omega)^{\Omega}(1-\Omega)^{(1-\Omega)}} \quad \text{and} \quad W_t^k = (W_t^{k,H})^{\Omega}(W_t^{k,E})^{(1-\Omega)}$$

Hence, the problem when employing the basic technology is:

$$\begin{aligned} \max_{\{k_t, l_t^k\}} \Pi_t^k &= P_t^k \left(\mathcal{A}_t \varphi(k_t, l_t^k)\right) - W_t^k l_t^k - R_t^k k_{t-1} - \theta(\tilde{R}_t - 1) W_t^k l_t^k \\ &= P_t^k y_t^k - C(W_t^k, R_t^k, \tilde{R}_t; y_t^k). \end{aligned} \tag{3.5}$$

Advanced technology: Apart from controlling the basic production plan, each entrepreneur also runs a single advanced technology project. For any such project, the production plan is complicated by the risk that it is hit by a liquidity shock[23] which may trigger project termination before it yields any return. We assume that liquidity risk $\tilde{\xi}_t^i$ is proportional to planned revenue $P_t^z \tilde{y}_t^z$ and that the normalized liquidity shock $\xi_t^i \equiv \frac{\tilde{\xi}_t^i}{P_t^z \tilde{y}_t^z}$ is distributed according to a continuous distribution function $G(\xi_t^i)$ with associated (strictly positive) density $g(\xi_t^i)$. As for the basic intermediate goods, there is a Cobb-Douglas aggregation of the respective labor inputs by households and entrepreneurs, and the technology is given by a Cobb-Douglas production function under constant returns to scale which allows for exogenous labor augmenting technological progress:

$$f(z_t, l_t^z) = (z_t)^{\alpha^z} \left((1+\gamma)^t l_t^z\right)^{1-\alpha^z}$$

An individual entrepreneur brings the amount E_t^i as private equity into her intermediary firm. The advanced production plan and the hedge against liquidity shocks are then determined as part of a constrained-efficient contract between the entrepreneur and the financial intermediary.

3.4.3 Financial intermediation

The financial intermediary (or equivalently, a perfectly competitive financial sector) receives the time t^- financial deposits $M_t - Q_t$ from the households as well as

[23]The liquidity shock admits a variety of interpretations. It can be thought of as a simple cost overrun, as a shortfall of revenue at an interim stage which could have been used as an internal source of refinancing or as adverse information relating to the project's end-of-period profitability.

lump-sum cash injections $\mathcal{J}_t$ from the monetary authority. These funds are supplied to the loans market at a gross nominal interest rate $\tilde{R}_t$. At the loans market, this supply meets the demand for financial assets which comes from two sources: First, entrepreneurial firms demand short term credit in order to meet the advance financing requirement for a fraction θ of their respective wage bills. Second, entrepreneurs demand liquidity D_t to be held as a buffer stock insuring their respective advanced technology projects. Hence, financial market clearing requires:

$$M_t - Q_t + \mathcal{J}_t = \theta W_t L_t + D_t, \tag{3.6}$$

where W_t and L_t are the aggregate wage rate and labor input across households and entrepreneurs and across the two intermediary technologies. Above condition simply stipulates that the equilibrium interest rate $\tilde{R}_t$ balances the supply of loans with the corporate demand for funds due to its advance financing requirement and its need for precautionary liquidity. The financial intermediary operates after aggregate uncertainty is resolved. While lending to projects employing the basic technology proceeds in a frictionless market, lending to advanced technology projects is complicated by an entrepreneurial moral hazard problem which is dealt with by a financial contract. Two key implications of this contracting scheme are that firm bankruptcy is an equilibrium phenomenon and that the intermediary must commit funds to individual advanced technology projects before these projects' idiosyncratic liquidity needs are known. Therefore, it is important to recognize that the financial intermediary is able to pool idiosyncratic risks across individual projects because, as a consequence, it is sufficient for the financial intermediary to break even on an individual credit relationship in expectation.[24] At the end of the period, the intermediary receives the returns on its lending and financial investment activity and pays the amount $\tilde{R}_t[M_t - Q_t + \mathcal{J}_t]$ to the households in return for their deposits. We next turn to a detailed description of the specific contracting problem in our model.

Financial contracting: Following Holmström and Tirole (1998), the sequencing of events underlying an individual advanced project's within-period[25] contracting

[24]Moreover, the intermediary's risk pooling capability also facilitates insurance of households' claims against individual advanced projects; the financial intermediary can therefore be thought of not only as matching supply of and demand for short-term credit, but also as a mutual fund pooling all household claims against advanced projects. The consequence is that, from an individual household's perspective, idiosyncratic risk ξ_t^i is hedged, while aggregate risk from $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$ remains relevant.

[25]Although the advanced production plan is conditional on the predetermined entrepreneurial equity position E_t^i, the factor demand problem itself is not dynamic because entrepreneurial asset accumulation proceeds mechanically and there is no intertemporal incentive provision. Moreover, since the financial contract turns out to be linear in E_t^i, the distribution of equity across entrepre-

problem can be decomposed into three stages. At *stage one*, after aggregate uncertainty with respect to $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$ is unveiled, the entrepreneur running an individual advanced project and holding an equity position E_t in it contracts with the financial intermediary to pin down its production plan and refinancing provisions. In particular, the refinancing provisions determine the degree of insurance against idiosyncratic liquidity risk.[26] Given s_t, a contract between the financial intermediary (outside investor) and the entrepreneur holding equity E_t prescribes (i) the scale of production as determined by factor employment (z_t, l_t^z), (ii) a state contingent continuation rule $\Gamma_t(\xi_t)$, and (iii) a state contingent transfer $\tau_t(\xi_t)$ from the entrepreneur to the investor. Hence, a generic contract takes the form $\mathcal{C}_t = \{z_t, l_t^z, \Gamma_t(\xi_t), \tau_t(\xi_t)\}$. A constraint on the contract is that it is written under *limited liability*, i.e. in case of project termination factors must be remunerated by the outside investor. At a subsequent interim stage (*stage two*) after the factor employment decisions have been made, the project is hit by an idiosyncratic liquidity shock ξ_t. If the shock is met by appropriate refinancing, the project can continue; otherwise it is liquidated. We assume that the liquidity shock is verifiable, but it is shown in Holmström and Tirole (1998) that nothing changes if only the entrepreneur observes the shock as long as she does not benefit from diverting resources. After the continuation decision, there is scope for moral hazard on the part of the entrepreneur in that she can exert effort to affect the distribution of production outcomes. Specifically, we make the extreme assumption that, conditional on continuation, exerting effort guarantees a gross return of $P_t^z \tilde{y}_t^z = P_t^z \mathcal{V}_t f(z_t, l_t^z)$ to production activity, while shirking leads to zero output, but generates a private (non-monetary) benefit B_t. We assume that the private benefit is proportional to project revenue conditional on survival; in particular, we have: $B_t = bP_t^z \mathcal{V}_t f(z_t, l_t^z) = bP_t^z \tilde{y}_t^z$ with $0 < b < 1$.[27] Finally, at *stage three*, the revenue from production accrues and payoffs are realized according to the rules stipulated in the financial contract. The financial intermediary engages in a continuum of contracts with all entrepreneurs operating the advanced technology; since liquidity risk is idiosyncratic, the intermediary is therefore able to pool the risk inherent in the investments across individual projects. As an implication, we can completely abstract from the effects of idiosyncratic uncertainty on the investor's evaluation of payoffs. Similarly, the entrepreneur who is exposed to her uninsured

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neurs does not matter and exact aggregation is possible. From now on, we will therefore drop the superscript i.

[26] It is important to realize that the financial contract is negotiated after fresh cash $\mathcal{J}_t$ has been injected into the economy. Consequently, our concept of corporate liquidity is real in the sense that there is no nominal rigidity which, upon an increase in the price level, would discount the effective insurance capacity of any given nominal amount of liquid assets; what is affected by nominal fluctuations, though, is its relative price, the liquidity premium $(\tilde{R}_t - 1)$.

[27] Note, however, that the specific value of $b > 0$ will not matter as long as the constrained-efficient contract to be derived in Appendix C.1.3 delivers an interior solution.

private equity risk is risk neutral and cares only about expected profits as long as she is active.

Hypothetically abstracting from both the entrepreneurial incentive constraint and the cost of obtaining liquidity at the interim stage, it is easy to see that there exists a unique cutoff value corresponding to a continuation policy which prescribes project continuation if and only if the liquidity shock is such that $\xi_t \leq 1$. The reason is that the stage one investment is sunk; hence, at the interim stage, it is optimal to refinance up to the full value of what can be generated in terms of revenue at the final stage. However, the need to take into account the incentive constraint and the costs of liquidity provision implies that the continuation policy will take the form:

$$\Gamma_t(\xi_t) = \begin{cases} 1, & \text{if } \xi_t \leq \hat{\xi}_t \\ 0, & \text{if } \xi_t > \hat{\xi}_t \end{cases}$$

for some cutoff value $\hat{\xi}_t < 1$. Hence, $\Gamma_t(\xi_t)$ is a simple indicator function with $\Gamma_t(\xi_t) = 1$ in case of continuation and $\Gamma_t(\xi_t) = 0$ in case of termination.

A constrained-efficient contract $\mathcal{C}_t = \{z_t, l_t^z, \Gamma_t(\xi_t), \tau_t(\xi_t)\}$ with (z_t, l_t^z) determining the scale of production, and $\Gamma_t(\xi_t)$ and $\tau_t(\xi_t)$ pinning down the state contingent policies for project continuation and transfers per unit of production costs $C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)$, respectively, then solves the following second best program of maximizing the entrepreneur's net return:

$$\max_{\mathcal{C}_t} \int \left\{\Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)\right\} dG(\xi_t) - E_t \tag{3.7a}$$

subject to a participation constraint for the investor that requires him to break even in expectation:

$$\int \left\{\tau_t(\xi_t) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) - \Gamma_t(\xi_t)\xi_t \tilde{R}_t P_t^z \tilde{y}_t^z\right\} dG(\xi_t) \geq C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) - E_t \tag{3.7b}$$

and a state-by-state incentive compatibility constraint for the entrepreneur:

$$\Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) \geq \Gamma_t(\xi_t) b P_t^z \tilde{y}_t^z \qquad \forall\, \xi_t, \tag{3.7c}$$

where $\tilde{y}_t^z = \mathcal{V}_t\,(z_t)^{\alpha^z}\,((1+\gamma)^t l_t^z)^{1-\alpha^z}$ is the project's output conditional on survival and:

$$\begin{aligned} C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) &= MC_t^z\left(W_t^z, R_t^z, \tilde{R}_t\right)\tilde{y}_t^z = \frac{1}{\mathcal{V}_t}\left(\frac{R_t}{\alpha^z}\right)^{\alpha^z}\left(\frac{[1+\theta(\tilde{R}_t-1)]W_t^z}{(1-\alpha^z)}\right)^{(1-\alpha^z)}\tilde{y}_t^z \\ &= [1+\theta(\tilde{R}_t-1)]W_t^z l_t^z + R_t^z z_t \end{aligned} \tag{3.8}$$

are the associated total costs which accrue when a output level of $\tilde{y}_t^z$ is targeted in case of survival; by constant returns to scale, the marginal cost $MC_t^z\,(\cdot)$ of increasing planned output $\tilde{y}_t^z$ is constant. Note how the specification of this problem, by means of the participation constraint (3.7b), incorporates the requirement that the investor who bears the risk of project failure be willing to finance the project, whereby the outside investor commits both the factor remuneration and the interim resources needed to meet the liquidity shock. Appendix C.1.3 shows that the solution to program (3.7) in terms of the optimal cutoff $\hat{\xi}_t^*$ is determined via the following first order condition:

$$\int_0^{\hat{\xi}_t^*} G(\xi_t)d\xi_t = \frac{MC_t^z(\cdot)}{P_t^z}\frac{1}{\tilde{R}_t} \tag{3.9}$$

This condition illustrates that the cost of providing liquidity at the interim stage, which has to be obtained in the financial market at the financial rate $\tilde{R}_t$, as well as the gap between prices and marginal costs $\frac{P_t^z}{MC_t^z(\cdot)}$ play a key role in shaping the optimal contract.

Implementation and aggregate liquidity demand: The key element of the solution to program (3.7) is the second best cutoff value $\hat{\xi}_t^*$ up to which refinancing needs will be covered such that production can proceed. In order to hedge against such liquidity shocks, it is necessary that outside investors commit funds at the initial contracting stage (*stage one*). The reason is that, by issuing corporate claims at the interim stage (*stage two*), it is not possible to raise enough funds because the entrepreneurial commitment problem limits the maximum return pledgeable to outside investors at $\hat{\xi}_t^0 = \frac{(1-b)}{\tilde{R}_t} < \hat{\xi}_t^*$. It is then a natural question to ask how the second best policy can actually be implemented at the initial contracting stage; moreover, in view of our modelling hypothesis that an economy's physical investment portfolio is affected by the degree to which risky production activities can be insured by means of corporate liquidity holdings, there arises the related question of whether there is a second best policy that features firms (rather than the intermediary) holding liquidity. These questions are dealt with in Appendix C.1.4. Here, suffice it to stress (i) that second best contracting can indeed be implemented via liquidity holdings at the firm level and (ii) that under financial intermediation, which efficiently economizes on the use of scarce liquidity by pooling liquidity risk across projects, the aggregate demand for liquidity is:

$$D_t = \left[\int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t)d\xi_t\right] P_t^z \tilde{y}_t^z \tag{3.10}$$

3.4.4 Market good

The market good is simply aggregated over the two technology-specific intermediate input goods supplied by the entrepreneurs:

$$y_t = \left(\zeta^{\frac{1}{\rho}} y_t^{k\,\frac{\rho-1}{\rho}} + (1-\zeta)^{\frac{1}{\rho}} y_t^{z\,\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}, \tag{3.11}$$

where y_t is the final output good and y_t^z and y_t^k are the two distinct intermediate input goods. The two parameters $0 < \zeta < 1$ and $\rho > 0$ determine the weight of each intermediate good in producing the aggregate market good and the elasticity of substitution of the two intermediates. Productive efficiency pins down the minimum cost combination of the final good firms' demands for intermediate input goods to be functions of the relative prices for the relevant intermediate input P_t^j, $j = k, z$ and for the final output P_t:

$$y_t^k = \zeta \left(\frac{P_t^k}{P_t}\right)^{-\rho} y_t \qquad \text{and} \qquad y_t^z = (1-\zeta)\left(\frac{P_t^z}{P_t}\right)^{-\rho} y_t \tag{3.12}$$

We assume perfect competition on the final goods market; therefore, the aggregate price level is determined by the marginal input cost, i.e. the intermediate good prices, which are constant from the final good firm's perspective. Consequently, zero profits imply:

$$P_t = \left(\zeta P_t^{k\,1-\rho} + (1-\zeta) P_t^{z\,1-\rho}\right)^{\frac{1}{1-\rho}} \tag{3.13}$$

For future reference, we also define the respective aggregates of the two factors of production, capital $K_t = k_t + z_t$ and labor $L_t = l_t^k + l_t^z$, as well as the elasticities of aggregate output with respect to the intermediate input levels:

$$\omega^y_{yk,t} \equiv \frac{dy_t/y_t}{dy_t^k/y_t^k} = \zeta^{\frac{1}{\rho}} \left(\frac{y_t^k}{y_t}\right)^{\frac{\rho-1}{\rho}} \qquad \text{and} \qquad \omega^y_{yz,t} \equiv \frac{dy_t/y_t}{dy_t^z/y_t^z} = (1-\zeta)^{\frac{1}{\rho}} \left(\frac{y_t^z}{y_t}\right)^{\frac{\rho-1}{\rho}} \tag{3.14}$$

3.4.5 Government policy

In order to close the model, a specification for government policy is needed. The focus of our analysis is not a normative one; therefore, to keep things simple, we will consider an exogenous process for monetary policy which consists of periodic injections $\mathcal{J}_t$ of money in the financial market. $\mathcal{J}_t$ is implicitly defined as $\mathcal{J}_t = (e^{mg_t} - 1)(M_t + A_t)$, where mg_t is the gross rate of money growth. Hence, the aggregate of nominal wealth held by households and entrepreneurs is updated according to:

$$(M_{t+1} + A_{t+1}) \;=\; e^{mg_t}(M_t + A_t)$$

The gross rate of money growth mg_t is assumed to evolve according to an autoregressive mean-reverting process:

$$mg_t = \rho_j mg_{t-1} + (1-\rho_j)mg^* + \epsilon_{j,t}, \qquad \epsilon_j \sim \mathcal{N}(0,\sigma_j^2),$$

where mg^* is the steady state level of money growth, which together with the economy's exogenous (balanced) growth rate γ determines the rate of inflation prevailing in steady state.

3.4.6 Equilibrium implications

The solution to the agents' optimization problems, the details on the implementation of financial contracting subject to entrepreneurial moral hazard as well as the definition of a competitive equilibrium are all contained in Appendix C.1. In the following, we put on record a set of important equilibrium implications which are informative with respect to the effects of monetary fluctuations on corporate liquidity demand and the composition of firms' physical investment. They are derived on the basis of the financial contracting scheme outlined in Section 3.4.3, which pins down the optimal amount of liquidity provision $\hat{\xi}_t^*$, and will be the object of our empirical analysis below.

- $\mathcal{H}1$: *Ceteris paribus*,[28] an increase in $\tilde{R}_t$ leads to a lower cutoff $\hat{\xi}_t^*$:

$$\frac{d\hat{\xi}_t^*}{d\tilde{R}_t} = -\frac{\int_0^{\hat{\xi}_t^*} G(\xi_t)d\xi_t}{\tilde{R}_t G(\hat{\xi}_t^*)} < 0 \tag{3.15}$$

Thus, quite intuitively, higher nominal interest rates $\tilde{R}_t$ imply less hedging against idiosyncratic liquidity shocks because the financial intermediary's participation constraint gets tighter in line with the increased costs of providing liquidity. In order to examine the effects of other changes in the economic environment on firms' liquidity demand, we establish two auxiliary results. *First*, increased volatility of the liquidity shock distribution $G(\cdot)$ in the sense of a mean-preserving spread implies a lower cutoff value $\hat{\xi}_t^*$; formally $\frac{d\hat{\xi}_t^*}{d\sigma_\xi} < 0$.[29] The intuition behind this result is that increased risk makes the option to terminate any given advanced project more valuable. The empirical prediction therefore is that firms operating in a more volatile environment

[28]The claimed result obtains if, to a first approximation, $\frac{P_t^z}{MC_t^z(\cdot)}$ remains constant. The result then follows from total differentiation of condition (3.9). That is, the results derived in the following are valid from a partial equilibrium perspective; taking into account general equilibrium effects does not change the qualitative (sign) properties of the relevant derivatives.

[29]Variations in the standard deviation σ_ξ need to be restricted to mean-preserving spreads. The result then obtains by partial integration; compare Mas-Collel, Whinston and Green (1995), chapter 6.

are insured less comprehensively. *Second*, situations where production by means of the advanced technology is more profitable, i.e. situations characterized by higher markups of prices over marginal costs $\frac{P_t^z}{MC_t^z(\cdot)}$ are predicted to feature a lower $\hat{\xi}_t^*$; formally $\frac{d\hat{\xi}_t^*}{d(P_t^z/MC_t^z)} < 0$.[30] The reason for the poorer insurance of more profitable projects is the contracting trade-off between ex ante and ex post rationing underlying the efficient choice of $\hat{\xi}_t^*$: While a more generous provision with liquidity has the advantage of withstanding larger shocks, the higher associated costs necessarily imply a lower stage one investment volume. Thus, for highly profitable projects, both contracting parties prefer to cut $\hat{\xi}_t^*$ in order to expand the project size. Based on these results, we can derive two additional hypotheses relating to the sensitivity of specific firms to fluctuations in the nominal interest rate.

- $\mathcal{H}2$: Increased production risk (in the form of a mean-preserving spread of the distribution $G(\cdot)$) accentuates the negative effect of $\tilde{R}_t$ on the cutoff $\hat{\xi}_t^*$:

$$\frac{d}{d\sigma_\xi}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) = \frac{d\hat{\xi}_t^*}{d\sigma_\xi}\frac{d}{d\hat{\xi}_t^*}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) < 0, \tag{3.16}$$

  where the inequality follows from the fact that $\hat{\xi}_t^*$ is decreasing in the volatility of the shock distribution and differentiation of expression (3.15) with respect to $\hat{\xi}_t^*$.

- $\mathcal{H}3$: Increased profitability accentuates the negative effect of $\tilde{R}_t$ on the cutoff $\hat{\xi}_t^*$:

$$\frac{d}{d(P_t^z/MC_t^z)}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) = \frac{d\hat{\xi}_t^*}{d(P_t^z/MC_t^z)}\frac{d}{d\hat{\xi}_t^*}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) < 0, \tag{3.17}$$

  where the inequality follows from the fact that $\hat{\xi}_t^*$ is decreasing in the price-to-marginal-cost ratio and differentiation of expression (3.15) with respect to $\hat{\xi}_t^*$.

Moreover, starting from the supposition that the economy's productive activity is organized based on a set of distinct technologies available to a continuum of entrepreneurial firms, we can infer a measure $\mathcal{T}_t$ of aggregate productivity. The argument put forward within the framework of our model is that $\mathcal{T}_t$ is not simply determined as an exogenous residual process, but also affected by endogenous shifts in the composition of economic activity. In detail, as shown in Appendix C.2, we derive our aggregate measure of TFP such that changes in $\mathcal{T}_t$ can be decomposed as follows:

$$\widehat{\mathcal{T}}_t = \omega_{yk,t}^y\widehat{\mathcal{A}}_t + \omega_{yz,t}^y\left(\widehat{\mathcal{V}}_t + \omega_{\hat{\xi}^*,t}^G\widehat{\hat{\xi}_t^*}\right), \tag{3.18}$$

[30] This follows from total differentiation of condition (3.9), for given $\tilde{R}_t$.

where $\widehat{x} \equiv \frac{dx}{x}$ and where $\omega^G_{\hat{\xi}^*} = \frac{g(\hat{\xi}^*)\hat{\xi}^*}{G(\hat{\xi}^*)}$ denotes the elasticity of the survival probability with respect to the cutoff value for liquidity shocks $\hat{\xi}^*$. Expression (3.18) illustrates how changes in $\mathcal{T}_t$ can be expressed as a weighted sum of changes in the technology-specific productivity levels $\mathcal{A}_t$ and $\mathcal{V}_t$. The endogenous weights attached to $\widehat{\mathcal{A}_t}$ and $\widehat{\mathcal{V}_t}$ are given by the elasticity terms $\omega^y_{yk,t}$ and $\omega^y_{yz,t}$ defined in (3.14), which underpins the importance of the sectoral composition of production activities; moreover, since the elasticity terms are formulated in terms of *realized* intermediate output levels, the effect of $\widehat{\mathcal{V}_t}$ is amended by the term $\omega^G_{\hat{\xi}^*,t}\widehat{\hat{\xi}^*_t}$ which reflects how the level of *realized* advanced sector output y^z_t (as opposed to $\tilde{y}^z_t$, the relevant quantity *conditional on survival*) responds to changes in the degree of insurance against liquidity risk provided to advanced projects. Thus, besides the exogenous processes $\mathcal{A}_t$ and $\mathcal{V}_t$, there are two endogenous sources of fluctuations in measured TFP: First, shifts in the allocation of physical investments (k_t, z_t) - an investment composition effect; and second, for a given composition of aggregate investment, changes in the effectiveness of converting hired factor inputs (z_t, l^z_t) into *realized* output y^z_t - an insurance effect in response to changes in the liquidity premium. Now, building on equations (3.15) and (3.18), the model's key implication with respect to aggregate fluctuations is obtained.

- $\mathcal{H}4$: For given realizations of $\mathcal{A}_t$ and $\mathcal{V}_t$, an increase in $\tilde{R}_t$ leads to a drop in TFP:
$$\frac{d\mathcal{T}_t}{d\tilde{R}_t} = \omega^y_{yz,t}\omega^G_{\hat{\xi}^*}\frac{d\hat{\xi}^*_t}{d\tilde{R}_t} < 0, \tag{3.19}$$
where the inequality follows from $\omega^y_{yz,t}, \omega^G_{\hat{\xi}^*} > 0$ and (3.15).

Finally, differentiation of equation (3.19) facilitates a prediction concerning the differential impact of nominal fluctuations across economies characterized by different production structures:

- $\mathcal{H}5$: Higher exposure to the advanced technology, as measured by a higher $\omega^y_{yz,t}$, implies a higher responsiveness of TFP to movements in $\tilde{R}_t$:
$$\frac{d}{d\omega^y_{yz,t}}\left(\frac{d\mathcal{T}_t}{d\tilde{R}_t}\right) = \omega^G_{\hat{\xi}^*}\frac{d\hat{\xi}^*_t}{d\tilde{R}_t} < 0, \tag{3.20}$$
which follows from $\omega^G_{\hat{\xi}^*} > 0$ and (3.15).

3.5 Quantitative model analysis

The model is calibrated to US time series at quarterly frequency, whereby we employ macroeconomic aggregates and amend them by industry-level data in order to calibrate the parameters that pin down the relative employment of "basic" versus "advanced" technologies. A description of the data as well as the details of our calibration exercise such as the specification of functional forms are contained in Appendix C.3. The calibrated benchmark set of parameters is summarized in Table 3.4. In order to assess the quantitative role of nominal shocks for aggregate fluctuations and in particular for the endogenous evolution of TFP, we now analyze the statistical properties of the model economy, employing the routines proposed by Sims (2001). As far as the monetary transmission mechanism is concerned, the effects of an unanticipated monetary expansion are twofold: First, there is a liquidity effect, recording as a drop in nominal interest rates on impact, and second, there is an inflationary effect which may take time to materialize. The induced dynamic pattern of nominal interest rates is key in shaping firms' investment with respect to its overall amount, but also with respect to its composition. Importantly, the compositional effects are associated with changes in aggregate productivity. Against this background, the main purpose of the following analysis is to examine within the framework of our model economy whether monetary shocks can indeed account for a sizeable fraction of fluctuations in TFP.[31] We approach this question based on a series of numerical experiments. *First*, we simulate the model for our benchmark calibration and confront the generated moments with empirical US business cycle statistics. *Second*, we consider the same model economy, but shut down money shocks as a source of nominal fluctuations; this exercise allows us to decompose the volatility of key macroeconomic aggregates - particularly of TFP - into the fractions that are attributable to money and technology shocks, respectively. *Finally*, we are interested in the steady state effects of increased nominal distortions, an issue that we approach by comparing the equilibrium allocations of alternative economies which are indexed by different rates of inflation along their balanced growth paths.

Empirical and simulated business cycle statistics: Table 3.5 documents empirical and simulated business cycle statistics. Of particular interest are standard deviations as well as contemporaneous correlations of several macroeconomic aggregates with real GDP. We point out that, empirically, aggregate productivity is procyclical with respect to real GDP, whereas both the level and the growth rate of TFP are negatively correlated with the rate of inflation (in terms of both the GDP deflator and CPI inflation) and different nominal interest rate measures, the own rate on $M2$ and the yield on corporate bonds.[32] Our benchmark model

[31] In contrast, it is not our principal objective to replicate salient features of the US monetary business cycle.

[32] The contemporaneous correlations for the growth rate of TFP, which are not reported in Table 3.5, are $\rho(\Delta\mathcal{T}, \pi\,(\text{dGDPdef})) = -0.23$, $\rho(\Delta\mathcal{T}, \pi\,(\text{dCPI})) = -0.22$, $\rho(\Delta\mathcal{T}, \tilde{R}\,(\text{M2})) = -0.15$ and $\rho(\Delta\mathcal{T}, \tilde{R}^{corp}) = -0.06$.

economy is characterized by a steady state quarterly rate of inflation of 1.31% and a remaining parametrization as summarized in Table 3.4. The linearized model is simulated, and the columns labelled "benchmark economy" in Table 3.5 report standard deviations as well as cross-correlations with aggregate output; for TFP, we also present cross-correlations with nominal interest rates and inflation. A comparison with the empirical statistics reveals that the model-generated standard deviations are consistent with the empirical pattern as far as relative magnitudes are concerned, but that the implied volatility of output falls short of its empirical counterpart, while the model statistics for hours worked and aggregate productivity reflect the increased (as compared to the data) volatility of the monetary variables. Turning to the contemporaneous correlations, we find that hours and aggregate investment display less procyclicality with aggregate output than observed in the data and that, counterfactually, a negative comovement of inflation and real GDP is predicted. On the other hand, the benchmark model generates interest rate correlations (0.07) which strike a balance with respect to the diverging sign pattern of the two analyzed nominal interest rate measures' correlations (0.24 and −0.17). Notably, also the comovement of TFP with real GDP is accurately replicated at 0.55 (versus 0.58 in the data). Turning to the correlations with nominal interest rates, the key statistic for our purpose is the negative contemporaneous correlation of TFP which the benchmark model predicts at −0.53 versus, depending on the interest rate measure, −0.29 or −0.44 in the data. The empirical correlation of TFP with the two different inflation measures is −0.35 or −0.22, whereas the benchmark model predicts that inflation and aggregate productivity do hardly comove over the cycle.[33] While not reported, we also note that inflation plays the role of a leading indicator for nominal interest rates; similarly, past money growth is found to be associated with higher nominal interest rates, whereas the contemporaneous correlation is negative due to the liquidity effect of monetary expansions. Taken together, these facts suggest a systematic effect of monetary policy on TFP, which is transmitted via fluctuations in the nominal interest rate and - according to our model - the associated changes in the composition of aggregate investment.

Variance decomposition and key correlations: To further assess the relevance of this mechanism, we resimulate the model, employing the same parametrization, but shutting down monetary shocks by setting $\sigma_j = 0$. This exercise facilitates a variance decomposition and is also informative with respect to the

[33]The explanation for this somewhat puzzling finding is related to the liquidity effect: Not only does an expansionary monetary innovation lead to inflation, but it also induces a decrease in nominal interest rates, thereby increasing aggregate productivity. Our rudimentary benchmark model features an excessively strong liquidity effect; therefore, the strongly positive comovement between inflation and measured TFP upon impact nets out the otherwise negative correlation between the two variables.

cyclical effects of monetary policy. The relevant statistics are also reported in Table 3.5 under the heading "$\sigma_j = 0$". Importantly, our quantitative analysis implies that 17.16% = (1.34 − 1.11)/1.34 of the fluctuations in aggregate productivity can be attributed to monetary policy shocks (see column four). Obviously, the quantitative importance of these shifts in aggregate productivity due to changes in the composition of aggregate investement critically depends on the relative importance of corporate liquidity demand in overall short-term credit, $\frac{d}{d+\theta wL}$; the latter ratio, in turn, is affected by the advance financing parameter θ. Specifically, pushing θ from its calibrated benchmark value of 0.25 towards zero implies that the relative importance of the demand for corporate liquidity to insure advanced technology investments increases. As a consequence, the sensitivity of aggregate productivity to fluctuations in the liquidity premium (the bulk of which can be attributed to monetary disturbances) is magnified. This is illustrated in column six which, for the alternative economy with $\theta = 0.05$, reports the fraction of TFP fluctuations to be traced to monetary shocks at 34.88%. In contrast, the standard deviation of aggregate investment is hardly affected across the alternative model economies. The same parameter variations have also important implications for the correlation pattern between macroeconomic aggregates as illustrated by the columns at the right end of Table 3.5. In particular, we point out that the contemporaneous correlation between TFP and nominal interest rates undergoes a sign switch from −0.53 to 0.15 when shutting down monetary shocks, while a decrease in θ is seen to intensify the negative comovement between the two variables. Similar conclusions can also be drawn with respect to the comovement of inflation and TFP.

Steady states: At a more fundamental level, distortions via increased rates of inflation and nominal interest rates affect the economy's real allocation also along a balanced growth path. Some important indicators for the induced distortions are summarized in Table 3.6, which compares steady state allocations across economies indexed by different rates of inflation. Moving from left to right, it can be seen that increased rates of inflation one-to-one feed into higher nominal interest rates and thus into a higher liquidity premium for insuring advanced sector production. The reason for this is that the liquidity premium faced by firms is effectively determined by the households who, due to their CIA constraint, require a higher compensation for carrying money from one period to the next one. Higher nominal rates then change the allocation in that (i) the composition of aggregate investment as measured by the ratio $\frac{z}{k}$ is shifted towards the basic technology, and (ii) the amount of corporate liquidity used to hedge advanced sector production decreases. The latter holds true both for the absolute real amount $d = \frac{D}{P}$ of corporate liquidity and two relevant measures of liquidity in relation to aggregate output, $\frac{d}{y}$, or the overall demand for short-term credit, $\frac{d}{d+\theta wL}$. The implication is that the survival probability $G(\cdot)$ of advanced projects successively decreases, which further aggravates the effect of the distorted composition of aggregate investment; this is evidenced by the ratio of realized sectoral outputs $\frac{y^z}{y^k}$ which declines by more than the relative allocation of physical capital. In line with the prediction of $\mathcal{H}4$, the relocation of resources induces a fall in aggregate productivity $\mathcal{T}$; as hinted above, this drop in TFP is the consequence of two things: (i) the shift in the composition of aggregate investment towards the basic technology, and (ii) the decreased insurance against liquidity risk in the advanced sector. Indeed, moving from an economy which is governed by a Friedman rule (first column) to an economy characterized by a money growth rate of 10% (column five) leads to a drop in TFP of 2.1%; similarly, moving from a non-inflationary steady state (column two) to the latter economy goes along with a drop in TFP of 1.7%. Finally, we mention that also some cyclical aspects of the alternative economies (indexed by their respective steady state rates of inflation) change as is evidenced by the correlation pattern of nominal interest rates presented in the last line of Table 3.6. Specifically, the adverse effects of interest rate shocks on TFP become more pronounced the higher the level of steady state inflation.

The results established on the basis of above experiments underpin that our proposed model may be a useful tool to understand how (inflation-driven) fluctuations in the nominal interest rate impinge on the cyclical behavior of macroeconomic aggregates and in particular on TFP. As far as the main phenomenon of interest, the negative causal effect of inflation and nominal interest rates on aggregate productivity, is concerned, the quantitative model analysis has demonstrated that not only cyclical fluctuations, but also level effects do play a quantitatively important role. Thus, at this stage, the model is consistent with the empirical evidence on the relationship and the inherent causality between macroeconomic aggregates documented in Section 3.3. The model has proposed a particular monetary transmission mechanism based on the qualitative composition of private investment portfolios and the importance of corporate liquidity holdings to hedge superior investment projects. Since this channel is identified neither via aggregate data nor the analysis of model-generated moments, we now investigate whether our specific predictions regarding firm behavior find empirical support in disaggregate data.

3.6 Empirical analysis of disaggregate data

In this section, we employ disaggregate US data to examine the specific microeconomic mechanism underlying our model. We do so in two steps, first exploiting industry-level data and then firm-level data.

3.6.1 Sectoral level

Data and methodology: Our model provides us with a set of firm-level predictions ($\mathcal{H}1$ - $\mathcal{H}3$) as well as aggregate implications ($\mathcal{H}4$ - $\mathcal{H}5$). It is straightforward to extend our one-sector model to a multi-sector setup, whereby each individual industrial sector is a replica of the representative production structure described in Section 3.4. The economywide TFP measures discussed in the context of $\mathcal{H}4$ and $\mathcal{H}5$ can then readibly interpreted as industry-specific productivity measures, and the contracting implications $\mathcal{H}1$ - $\mathcal{H}3$ do apply not only for individual firms, but also for industrial sectors. Hence, we can empirically test our hypotheses by means of industry-level data. In particular, as an implication of $\mathcal{H}2$, we are led to hypothesize that the response in terms of the cutoff $\hat{\xi}^*$ to movements in the nominal interest rate is stronger for firms operating in more volatile industries. A positive correlation between the rate of inflation and nominal interest rates[34] and the fact - compare equation (3.18) - that a lower $\hat{\xi}^*$ ceteris paribus leads to lower TFP-growth then together imply that the negative relation between TFP-growth and inflation is expected to be stronger in more volatile industrial sectors. In addition, we presume that firms operating in more productive sectors in terms of their historically realized TFP-growth have had access and are more exposed to superior investment opportunities and therefore depend more heavily on corporate asset holdings to insure against liquidity risk. Indeed, for given $\tilde{R}$, equation (3.8) delivers a link between the technology component $\mathcal{V}$ available to a firm on the one hand and its marginal cost MC^z and therefore its profitability $\frac{P^z}{MC^z}$ in case of survival on the other hand; the intuitive implication is that high productivity growth goes along with high potential profitability. Hence, from $\mathcal{H}3$, profitable firms operating in industries with high realized productivity growth are expected to react more sensitively to nominal fluctuations, and, from $\mathcal{H}5$, such fluctuations should affect sectoral TFP-growth more severely in industries with a better historical productivity performance.

We apply 3-digit industry-level data for the US to investigate these hypotheses. The productivity of US industrial sectors is measured by the yearly growth rate of real value added per industry from the UNIDO (2002) industrial statistics database. The yearly data are available for 28 industries from 1963-2000.[35] The classification of 3-digit US industries with respect to average volatility (standard deviation) and average growth of productivity in our sample are reported in Table 3.7. The correlation coefficient between these two rankings is positive 0.23 (s.e.=0.03) and sig-

[34] As already mentioned above, for unfiltered data, the correlation coefficient between CPI inflation and the nominal interest rate (Moody's Seasoned Aaa Corporate Bond Yield) is 0.42 (0.55) at yearly (quarterly) frequency.

[35] We have to confine ourselves with yearly data since, to our knowledge, quarterly data on value added at industry level are not available. Moreover, note that we deflate the value added series in each sector with the economywide GDP-deflator.

nificantly different from zero at a 1% level according to Spearman's rank correlation test. Hence, independence of both rankings is rejected, confirming that more volatile sectors tend to be characterized by higher average productivity growth.[36] Therefore, identifying industries that are highly exposed to the advanced technology (in the sense of a high ω^y_{yz}) with volatile and strongly growing sectors, we operationalize our empirical analysis by means of $\mathcal{H}5$: We divide the sample according to the median, the first and the fourth quartile of both measures. According to our theoretical model, the differential impact of inflation on TFP-growth across the relevant subsamples should result from the different sensitivity of corporate liquidity holdings in response to nominal fluctuations and is expected to be more pronounced in the 14 (7) industries whose volatility/average productivity growth is above the median (in the first quartile). We control for industry-specific fixed effects in all estimations. Since the first lag of the growth rate (or level) of value added is not significant at conventional levels in any specification, we employ a static panel estimation. That is, we estimate the following model:

$$y_{i,t} = \alpha + \beta_1 \pi_{t-1} + \beta_2(\pi_{t-1} * DV_i) + \beta_3 X_t + \eta_i + \epsilon_{i,t}, \qquad i = 1, 2, ..., N, t = 1, 2, ..., T, \tag{3.21}$$

where $y_{i,t}$ is the growth rate of real value added per industry, π_{t-1} the first lag of inflation, DV_i a dummy which amounts to one for industries with an above median (first quartile) volatility/mean, X_t a vector of aggregate control variables, $N = 28$ the number of cross-sections, $T = 38$ the number of time-periods, η_i industry-specific fixed effects, $\epsilon_{i,t}$ the error term and α and β parameters to be estimated.[37] We cluster the error terms at the industry level so that the standard errors are robust to within-group (serial) correlation.[38] Inflation is measured as the change in the economywide consumer price index; we include the first lag of inflation due to the potential endogeneity of contemporaneous measures. Furthermore, we include the contemporaneous level and the first lag of the growth rate of GDP ($GDP - growth$), the private investment share ($inv - share$) and the amount of overall credit ($credit$) as control variables. The latter variable is often used as a proxy for the degree of financial market development in the literature.

Results: The first column in Table 3.8 reports the correlation between the first lag of inflation and the growth rate of real value added for the full sample. We find that a 1% increase in the economywide rate of inflation triggers, on average, a drop in

[36] Among the ten most volatile sectors, we find industries such as professional & scientific equipment, petroleum refineries, plastic products, industrial chemicals, iron and steel or non-ferrous metals. In contrast, the four least volatile sectors are food products, other chemicals, beverages and printing and publishing.

[37] We also included a linear time trend, but it is not significant at conventional levels. Moreover, allowing for year fixed effects would have considerably reduced the degrees of freedom.

[38] Consequently, our results are not subject to the caveat raised by Moulton (1990).

the sectoral growth rate of real value added by 0.96% after controlling for changes in (lagged) GDP-growth, the private investment share and the overall supply of credit. The next two columns contrast the sensitivity of value added growth with respect to inflation in high and low volatility sectors (above/below median). Consistent with $\mathcal{H}2$, we detect that the negative impact of inflation is significant in both subsamples, but on average 61% higher in the 14 highly volatile sectors. In order to test for a statistical significance of the difference between both coefficients, we interact the lag of inflation with a dummy variable which amounts to one for high volatility industries (according to the median) and zero otherwise. Column four reveals that the interaction is negative and significant on a 10% level. That is, the distorting impact of an 1% increase in inflation aggravates, on average, by 0.32% if we focus on high volatility as opposed to low volatility sectors. This effect is even more pronounced if we compare the sensitivity in the seven most volatile sectors with the one in the residual 21 sectors (column five). In particular, the sensitivity of value added growth per industry with respect to inflation is, on average, 76% higher in the seven most volatile sectors. The difference is significant on a 5% level. Thus, as predicted by $\mathcal{H}2$, we are able to link the inflation-sensitivity of sectoral TFP-growth to the average sectoral volatility of productivity growth per industry. Columns six to seven of Table 3.8 classify the impact of inflation on productivity growth according to the median and first quartile of the observed average productivity growth of a given industry in the sample. In accordance with $\mathcal{H}3$ and $\mathcal{H}5$, column six reports that the negative impact of inflation is more pronounced in industries whose average productivity growth is above the sample median. Yet, the difference is not significant at conventional levels. Moreover, the coefficient is neither significant nor even positive if we focus on the seven sectors that experienced the highest average productivity increase in the sample.

Overall, the results emerging from the analysis of industry-level data corroborate our theoretical predictions that the negative effect of inflation on TFP-growth varies systematically with the riskiness of physical investment portfolios across industrial sectors as measured by the sectoral volatility of value added growth. In particular, we interpret these findings as supportive for our theoretical model's distinction between the basic technology, which is normalized to be free of liquidity risk, and the advanced technology, where there is a superior growth potential, but where idiosyncratic liquidity shocks give rise to a corporate demand for (partial) insurance against such risk. In the next subsection, we will revisit the specific implications arising from this setup on the basis of firm-level data.

3.6.2 Firm level

Data and methodology: Firm-level data allow for the most direct test of the specific transmission mechanism proposed by our model. Specifically, our theory predicts that firms react to nominal distortions which increase the liquidity premium by reducing their liquidity holdings used to hedge advanced investment projects ($\mathcal{H}1$) and by shifting their investment portfolios towards more secure, but also less productive projects. Thus, we expect that increased corporate liquidity holdings augment the investment in superior projects, while increased nominal interest rates, notably as a consequence of higher (expected) rates of inflation, reduce corporate liquidity holdings and trigger an adverse investment composition effect.

In order to test these hypotheses, we match the relevant variables employed in Section 3.3 with US firm-level data at quarterly as well as yearly frequency from the Compustat database. The latter data relate to the balance sheets of US non-financial firms and cover the effective time periods 1989:1-2000:4 and 1970-2000, respectively. In detail, we include the following firm-level data: R&D expenses, the amount of corporate liquidity measured as the sum of cash and marketable securities (*corp. liquidity*) and the amount of total assets (*assets*).[39] Here, R&D is used as a proxy for investment in superior technologies.[40] The *assets* variable, in turn, reflects overall corporate assets and thus controls for firm size. As hinted above, we use the US CPI-based rate of inflation and the yield on corporate bonds to investigate the effect of these macroeconomic variables on firm-level liquidity and investment portfolios.[41] In addition, where available, we exploit information on individual firms' S&P credit rating (*spdrc*)[42] as an additional control variable to isolate the effect of firm-specific credit conditions relative to the aggregate measure for the lending rate faced by non-financial firms.

In this context, we again point out the empirical evidence provided by Opler et al. (1999) based on yearly US firm-level data for 1970-1993. The authors proxy a firm's investment opportunities by its market-to-book value and/or its expenses for R&D, respectively; the risk associated with a firm's cash flow is measured by the standard deviation of its cash flows. The study finds that the value of liquid assets (cash and marketable securities) relative to total net assets averages at 18% for US non-financial firms. Furthermore, it establishes that firms with higher growth opportunities and riskier cash flows hold on average more liquid assets.[43] We see these

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[39] The qualitative results are robust to the inclusion of additional firm-level control variables such as operating income before taxes and interest payments, the amount of long-run outstanding debt or interest payments.

[40] If we interpret investment in superior technologies as investment in new technologies, while investment in less productive projects reflects production with established technologies, R&D expenses are the most appropriate candidate for an approximation of advanced investments projects.

[41] We stress that our standard errors are robust to serial correlation and hence are not subject to the caveat raised by Moulton (1990).

[42] The variable is an index number, ranging from 1 to 30 in our sample, whereby a higher value corresponds to a poorer credit rating.

[43] Notice that these latter findings relate to a sample comprising firms irrespective of the industrial sector they belong to. In contrast, our own empirical prediction ($\mathcal{H}2$) was empirically tested by

empirical findings as strongly supportive of the relevance of corporate liquidity holdings for the purpose of insuring superior, but risky production activities. Against this background, we extend the analysis in Opler et al. (1999) by investigating the impact of inflation and nominal interest rates on corporate liquidity holdings and firm-level R&D expenses.

We have a balanced panel of over 150000 (97000) observations at quarterly (yearly) frequency.[44] We employ the Arellano and Bond (1991) GMM difference ($GMM - dif$) as well as the Blundell and Bond (1998) GMM system estimator ($GMM - sys$) because of the significance of the lagged dependent variable (e.g. lagged R&D levels).[45] These estimation procedures are based on the general method of moments (GMM) and are constructed to yield consistent estimates in dynamic panels. In particular, Arellano and Bond (1991) estimate a dynamic panel data model in first differences and apply appropriate lagged levels as instruments for the first differences of the endogenous variables. These are valid instruments if (i) the time-varying disturbance $\epsilon_{i,t}$ is not serially correlated, and (ii) the explanatory variables $X_{i,t}$ are weakly exogenous.[46] In all estimations, we employ heteroscedasticity- and serial correlation robust standards errors. Finally, note that the mix of macroeconomic and microeconomic data allows for an inspection

means of industrial subaggregates. Hence, there is no inconsistency between the results in Opler et al. (1999) and our own findings reported in Section 3.6.1.

[44]Unfortunately, the S&P credit rating index is only available for roughly 12000 time observations.

[45]Similarly, Aghion et al. (2006) apply a (country-) panel estimation based on yearly data to test for business cycle effects of volatility.

[46]In other words, considering the following dynamic panel data model in first differences:

$$y_{i,t} - y_{i,t-1} = \alpha(y_{i,t-1} - y_{i,t-2}) + \beta(X_{i,t} - X_{i,t-1}) + (\epsilon_{i,t} - \epsilon_{i,t-1}), \quad i = 1, 2, ..., N, t = 3, 4, ..., T,$$

the basic assumptions of Arellano and Bond (1991) are $E[y_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0$, $E[X_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0$ for $s \geq 2; t = 3, ...T$, where $y_{i,t}$ is the dependent variable, $X_{i,t}$ a vector of endogenous and exogenous explanatory variables, N the number of cross-sections, T the number of time-periods, $\epsilon_{i,t}$ the error term and α and β parameters to be estimated. In addition, Blundell and Bond (1998) apply supplementary moment restrictions on the original model in levels, whereby lagged differences are used as additional instruments for the endogenous and predetermined variables in levels. [For practical purposes, we impose one instrument for each variable and lag distance (collapse option), rather than one for each time period, variable, and lag distance in the case of the GMM system estimator. This restriction on the IV-matrix reduces efficiency, but increases the number of overidentifying restrictions which are used to test for the validity of the instruments (Hansen test). Moreover, we limit the number of lags to six in the case of the Arellano-Bond estimator.] Given that $E[y_{i,t}, \mu_i]$ is mean stationary, the Blundell and Bond (1998) estimator incorporates the additional moment restrictions $E[(y_{i,t-1} - y_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0$, $E[(X_{i,t-1} - X_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0$, which requires the additional assumption of no correlation between the differences of these variables and the country-specific effect. The authors show that this procedure is more efficient if explanatory variables are persistent; however, the estimator requires mean stationarity.

of causality. More specifically, the coefficient of inflation reflects the causal impact on an individual firm's (marginal) R&D expenses since the latter have no feedback effect on the aggregate level of inflation.

Results: In all estimations, we reject the presence of second-order autocorrelation. Furthermore, the Hansen test of overidentifying restrictions never rejects the validity of the instruments. Hence, all estimation specifications appear to be well-specified.[47] Table 3.9 summarizes our main results for the dynamic panel estimations at quarterly frequency.[48] In the first two columns, we use the amount of corporate liquidity as the dependent variable. The first column reports a negative coefficient of inflation, which is not significant at conventional levels, however. The second column displays a negative impact of the nominal interest rate on corporate liquidity holdings, which is significant on a 5% level. This coefficient suggests that, averaging across firms, a 1% increase in the nominal interest rate reduces liquidity holdings per firm by almost 1.4 million US$ in the same quarter. In particular, our estimation results are consistent with proposition $\mathcal{H}1$ derived in the context of the agency problem underlying our theoretical model. In both cases, we control for firm size (total assets), which - not surprisingly - has a positive effect on liquidity holdings.

The remaining columns of Table 3.9 have R&D expenses per firm as the dependent variable. The third column illustrates that inflation has a negative causal impact on firm-level investments in R&D; the coefficient is significant on a 5% level. Keeping the amount of total assets fixed, a 1% increase in inflation reduces R&D expenses per firm on average by 0.9 million US$. Moreover, as evidenced by the positive coefficient on total assets, larger firms invest more in R&D. In view of the comprehensive empirical evidence[49] that larger firms have better outside financing opportunities, this suggests that R&D investments are constrained by a firm's financing opportunities. Importantly, the fourth column demonstrates that the distorting effect of inflation declines if we control for the amount of corporate liquidity holdings. We find that the coefficient of inflation is cut by one half and not significant any more at conventional levels. At the same time, an increase in liquid assets per firm enhances investments in superior technologies; the corresponding coefficient is significant on a 1% level.[50]

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[47] As explained above, inflation and the nominal interest rate are considered as exogenous variables. The microeconomic variables are considered as (potentially) endogenous.

[48] The same qualitative results obtain also for OLS or static fixed effects estimations. However, both estimators are inconsistent in our setting due to the presence of aggregate variables in a dynamic disaggregate panel framework.

[49] Compare e.g. Hubbard (1998) and the references therein.

[50] Note that all qualitative results are also robust to the inclusion of industry rather than firm fixed effects; results are available from the authors upon request.

In the next two columns of Table 3.9, we repeat the same exercise, using the yield on corporate bonds rather than inflation as the measure of nominal distortions. The nominal interest rate has a negative impact on firm-level R&D expenses; the corresponding coefficient is significant on a 1% level. Again, the effect is smaller in absolute terms and loses significance at conventional levels if firm-level liquid assets are controlled for. Finally, in the last column of Table 3.9, again resorting to the rate of inflation as the key explanatory variable, we include the S&P credit rating index as an additional control variable. This reduces the effective sample to 7482 observations since the rating is only available for a subset of firms. The coefficient of the index reveals that a downgrading in the credit rating reduces R&D expenditures, though not significantly. We point out that the adverse effect of inflation on R&D expenses increases and is even significant at a 1% level for the relevant subset of firms. Overall, the quarterly firm-level results are consistent with the specific transmission mechanism proposed in our theoretical model in that increases in inflation or interest rates reduce investment in advanced projects (R&D). Moreover, as demonstrated by the differential coefficient pattern depending on whether corporate liquidity holdings are switched on or off as a control variable, such liquidity buffer stocks are indeed a quantitatively relevant transmission channel for the effect of nominal fluctuations on the composition of firms' investment portfolios.

In Table 3.10, we report the firm-level evidence for data recorded at yearly frequency. The outline of the results follows the same logic as for Table 3.9. The first two columns reveal that an increase in either inflation or nominal interest rates substantially reduces corporate liquidity holdings. The two relevant coefficients are both significant on a 5% level. Moreover, inflation reduces R&D investment per firm. At a yearly frequency, the corresponding coefficient suggests that a 1% increase in inflation reduces a firm's R&D expenses on average by 0.47 million US$.[51] The distortionary effect of inflation declines by 20% if we additionally control for liquidity holdings per firm.[52] The direct effect of corporate liquidity holdings on R&D is close to the one at quarterly frequency and significant at a 1% level. In contrast to the quarterly findings, the coefficient of the nominal interest rate in the R&D regression, though still negative, is not significant at conventional levels; there is even a sign switch if liquid assets are controlled for. In the last two columns of Table 3.10, we systematically exploit the information of the S&P credit rating. Specifically, we split the sample into two subsets: (i) firms with a "sound" credit ranking (below 12) and (ii) firms with a "poor" one (above 12). Following the logic of our model, one would expect that the negative impact of inflation on R&D is more pronounced

[51] We employ the Arellano-Bond estimator since the coefficient of the lagged dependent variable is close to one, indicating problems with the stationarity of R&D at yearly frequency which would contaminate the Blundell-Bond estimator.

[52] Yet, the decline in the inflation-coefficient is not statistically significant.

for firms with worse access to external finance since the precautionary holding of marketable assets for the purpose of hedging liquidity risk becomes more important. Indeed, columns seven and eight display that the distortionary impact of inflation is six times higher for firms with a poor credit rating. Furthermore, a deterioration in the credit rating has a negative direct effect on R&D investments for the subset of firms with a relatively bad credit rating, while the effect is not significant for the subset of better-rated firms.

Summing up, the firm-level results show that inflation has a negative impact on firm-level investment in superior technologies. However, this effect disappears if corporate holdings of cash and marketable securities and individual firms' outside financing opportunities are controlled for. Thus, the impact of inflation on compositional investment decisions at the firm-level is actually due to variations in a firm's liquidity holdings and outside financing opportunities. Together with the results from the previous industry-level analysis, the empirical firm-level findings provide strong evidence in favor of the microeconomic mechanism underlying our theoretical propositions regarding the aggregate relation between inflation and investment composition-driven TFP-growth at business cycle frequency.

3.7 Concluding remarks

The main contribution of this paper is to document a negative causal effect of inflation on TFP at business cycle frequency and to propose a model to structurally rationalize this effect. On the basis of US quarterly and yearly time series data, we provide detailed empirical evidence supporting the hypothesis that nominal distortions have a negative effect on TFP-growth. We then propose a monetary business cycle model allowing for endogenous technology choice between a safe, but return-dominated technology and a superior technology which yields higher expected returns, but is subject to idiosyncratic liquidity shocks. Insurance against such liquidity risk is possible by holding a buffer stock of liquid assets, but an agency problem prevents complete insurance, whereby the scope for insurance is endogenously determined via the relative price for liquidity. In this environment, we demonstrate how nominal fluctuations affect not only the overall amount, but also the composition of aggregate investment and the degree to which advanced investments are hedged against liquidity risk. The direct consequence is an effect on aggregate productivity. Next, we show that the proposed monetary transmission mechanism as well as the model's equilibrium implications for corporate liquidity holdings and the composition of physical investment are consistent with US industry-level and firm-level panel data. Using industry-level data, we find that sectoral TFP-growth responds more sensitively to nominal fluctuations (i) in more volatile sectors and (ii) in sectors that are characterized by a relatively high historical TFP-growth. From firm-level data, we infer that investments in superior technologies, proxied by firm-level R&D expenses, (i) decline if the level of inflation or nominal interest rates increases and (ii) are positively related to corporate liquidity holdings. We regard these empirical findings as strongly supportive of our proposed transmission mechanism.

On the basis of numerical exercises we infer that monetary policy shocks can account for a significant proportion of the variations in TFP. In fact, the benchmark calibration of our model implies that some 17% of the variability in aggregate productivity can be attributed to monetary shocks. Consequently, our findings suggest that the role of monetary policy shocks for macroeconomic fluctuations has been underestimated. While the present paper's focus is on the business cycle implications of the investment-composition driven effects of monetary shocks, both the empirical analysis of US aggregate data and the analysis of our model indicate that also higher steady state rates of inflation have adverse implications on the evolution of TFP. In a companion paper, Evers, Niemann and Schiffbauer (2007), we therefore elaborate on the endogenous growth implications of our proposed transmission mechanism and, using country-level panel data, identify a robust negative causal effect of inflation on long-run TFP-growth. Our explanation is that inflation acts as a tax on the provision of liquidity to the corporate sector and thereby affects not only the capital accumulation decision, but also the technology choice decision which shapes the evolution of aggregate productivity.[53]

On more general grounds, the striking empirical evidence of a negative causal influence of monetary variables (inflation and nominal interest rates, respectively) on both short-run fluctuations and long-run growth rates of TFP fundamentally questions the orthodox modelling strategy of treating money supply shocks and shocks to aggregate technology, identified as a residual category labelled TFP, as orthogonal.[54] Against this background, there is a need for more theoretical and empirical work in order to better understand the implications of compositional variations in the utilization of production factors and their dependence on nominal macroeconomic conditions. In the present paper, we have stressed one relevant margin; complementary issues relating to government policies other than monetary policy as well as to the market environment in which (heterogenous) firms dynamically interact deserve particular attention.

[53]Compare Erosa (2001) for a similar argument.

[54]Implicitly, this insight already underlies the work by Fischer (1993).

Table 3.1: US aggregate quarterly and yearly data: Inflation & TFP-growth

unrestricted VAR

	quarterly	yearly		quarterly	yearly
dependent variable: TFP-growth			**dependent variable: inflation**		
L.TFP-growth	-.0656	.0806	L.TFP-growth	-.0572	-1.20**
	(-.56)	(.22)		(-.93)	(-2.22)
L.inflation	-.1761**	-.2399***	L.inflation	.8486***	.8760***
	(-2.24)	(-2.76)		(20.68)	(6.81)
L.GDP-growth	-.0727	-.2582	L.GDP-growth	.0382	1.24***
	(-.81)	(-1.12)		(.82)	(3.64)
L.inv-share	-.1000***	-.0231	L.inv-share	.0289	-.1244
	(-2.61)	(-.13)		(1.45)	(-.46)
dependent variable: GDP-growth			**dependent variable: inv-share**		
L.TFP-growth	-.6108***	.6148	L.TFP-growth	-.5447***	.5393
	(-4.00)	(0.92)		(-5.37)	(1.30)
L.inflation	-.2238**	-.2596	L.inflation	.0543	.0473
	(-2.19)	(-1.62)		(.80)	(.48)
L.GDP-growth	.6053***	-.3055	L.GDP-growth	.5528***	-.0866
	(5.23)	(-.72)		(7.19)	(-.33)
L.inv-share	-.1335***	-.0479	L.inv-share	.8149***	.5862***
	(-2.69)	(-.14)		(24.72)	(2.83)

Granger causality test

	quarterly	yearly		quarterly	yearly
dependent variable: TFP-growth			**dependent variable: inflation**		
inflation	0.025**	0.006***	TFP-growth	0.351	0.026**
GDP-growth	0.415	0.262	GDP-growth	0.412	0.000***
inv-share	0.009***	0.899	inv-share	0.147	0.643
dependent variable: GDP-growth			**dependent variable: inv-share**		
TFP-growth	0.000***	0.360	TFP-growth	0.000***	0.195
inflation	0.028**	0.105	inflation	0.423	0.634
inv-share	0.007***	0.886	GDP-growth	0.000***	0.742

Lag length selection criteria

quarterly	167 Observations	AIC: 4. lag	HQIC: 1. lag	SBIC: 1. lag
yearly	30 Observations	AIC: 1. lag	HQIC: 1. lag	SBIC: 1. lag

We exclusively report the effects on TFP-growth. Always include a constant. 1960:1 - 2001:4 quarterly and 1970-2000 yearly data. Endogenous variables: inflation, GDP-growth, private investment share. Heteroscedasticity-robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.
Test statistics are reported in p-values.

Table 3.2: US aggregate yearly data: Inflation, corporate interest rates, investment composition, corporate liquidity & TFP-growth

	TFP-growth OLS	GMM-IV	GMM-IV	*first stage*[1)] R&D/assets OLS	TFP-growth OLS	GMM-IV	GMM-IV	*first stage*[1)] liquidity/assets OLS
R&D/assets	2.04***	1.69***	2.66***					
	(2.76)	(2.92)	(2.99)					
liquidity/assets					.7279**	1.13***	1.27*	
					(2.53)	(2.74)	(1.94)	
L.inflation				-.0604***				-.1643***
				(-3.20)				(-3.07)
assets	-.0045		-.0030	.0022***	-.0040		-.0053	.0048**
	(-.96)		(-.83)	(2.71)	(-.77)		(-.98)	(2.09)
oper. income	-.0145		-.0023	.0050	-.0074		-.0005	.0015
	(-.63)		(-.16)	(1.33)	(-.73)		(-.05)	(.16)
long-debt	.0273		.0108	-.0128***	.0257		.0281	-.0277***
	(1.45)		(.80)	(-3.12)	(1.19)		(1.61)	(-3.30)
inv-share	.1792				.1083			
	(.89)				(.61)			
gov-share	-1.61*				-1.39			
	(-1.91)				(-1.36)			
Observations	30	30	30	30	30	30	30	30
1. serial-cor.	.466	.464	.875	.219	.985	.495	.565	.065
2. serial-cor.	.464	.503	.346	.328	.826	.318	.447	.620
Hansen-test	-	.694	.315	-	-	.742	.573	-

1) We exclusively show the results of the first stage regression for the first lag of inflation; the correlation coefficient between inflation and corporate interest rates is 0.42.

Exog. variables (IVs): first and second lags of inflation and interest rates (Moody's Seasoned Aaa Corporate Bond Yield).

Additional exogenous control variables in the 1. and 2. stage for robustness check:

corporate assets, corporate operating income, corporate long-run debt, corporate interest expenditures.

Heteroscedasticity-robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.

Null-hypothesis of well-specified model. Test statistics are reported in p-values.

Always include a constant. 1970 - 2000 yearly data.

Table 3.3: US aggregate quarterly data: Inflation, corporate interest rates, investment composition, corporate liquidity & TFP-growth

				first stage[1)]				*first stage*[1)]
	TFP-growth			R&D/assets	TFP-growth			liquidity/assets
	OLS	GMM-IV	GMM-IV	OLS	OLS	GMM-IV	GMM-IV	OLS
R&D/assets	.5308**	.8768*	1.01*					
	(2.22)	(1.73)	(1.81)					
liquidity/assets					-.0025	.0365	.0481	
					(-.04)	(1.05)	(1.26)	
L.inflation				-.1861***				-2.95***
				(-2.87)				(-4.08)
assets	.0001		.0006	-.0002	.0001		-.0002	.0120***
	(.08)		(.44)	(-.51)	(.04)		(-.11)	(2.87)
oper. income	-.0096		-.0207*	.0151***	-.0034		-.0045	-.0223
	(-.86)		(-1.94)	(3.71)	(-.29)		(-.47)	(-.64)
long-debt	.0010		.0006	-.0006	.0009		.0029	-.0692***
	(.18)		(.10)	(-.34)	(.16)		(.46)	(-3.57)
inv-share	-.0004				-.0001			
	(-.56)				(-.13)			
gov-share	.0052				.0028			
	(.70)				(.39)			
Observations	48	48	48	48	48	48	48	48
1. serial-cor.	.303	.358	.331	.174	.551	.318	.325	.405
2. serial-cor.	.869	.407	.369	.069	.930	.333	.646	.011
Hansen-test	-	.482	.555	-	-	.485	.490	-

1) We exclusively show the results of the first stage regression for the first lag of inflation; the correlation coefficient between inflation and corporate interest rates is 0.55.

Exog. variables (IVs): first and second lags of inflation and interest rates (Moody's Seasoned Aaa Corporate Bond Yield).

Additional exogenous control variables in the 1. and 2. stage for robustness check:

corporate assets, corporate operating income, corporate long-run debt, corporate interest expenditures.

Heteroscedasticity-robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.

Null-hypothesis of well-specified model. Test statistics are reported in p-values.

Always include a constant. 1960:1 - 2001:4 quarterly data.

Table 3.4: Calibrated parameter values

β	σ	μ	γ	α^k	α^z	δ	θ	ϕ	Ω	χ	η
0.98	2	0.167	0.0037	0.31	0.31	0.0112	0.25	12.5	0.95	1.26	0.97
ζ	ρ	ρ_a	σ_a	ρ_v	σ_v	ρ_{av}	ρ_j	σ_j	b	μ_ξ	σ_ξ
0.73	1.66	0.79	0.0075	0.66	0.0111	0.67	0.35	0.0069	0.15	-0.75	0.75

Table 3.5: Cyclical statistics, variance decomposition and contemporaneous correlations

Variable	US econ.	benchm. econ.	$\sigma_j = 0$	% change[1)]	$\sigma_j = 0$ $\theta = 0.05$	% change[2)]	US econ.	benchm. econ.	$\sigma_j = 0$	$\theta = 0.05$	$\sigma_j = 0$ $\theta = 0.05$
	standard deviation (%)						contemp. corr. with real output (GDP)				
GDP	1.54	1.20	1.19	0.83	1.19	2.46	1.00	1.00	1.00	1.00	1.00
HOURS	1.74	2.12	1.66	21.70	1.66	41.34	0.88	0.33	0.38	0.31	0.38
INV	5.60	5.61	5.59	0.36	5.59	1.41	0.93	0.71	0.71	0.71	0.72
$\tilde{R}$ (M2) $\tilde{R}^{corp}$	0.63 0.68	1.53	0.04	97.72	0.08	97.03	0.24 −0.17	0.07	0.00	0.13	0.00
Δ M2	0.69	0.67	0.00	100.00	0.00	100.00	-0.30	-0.10	0.00	-0.16	0.00
π (dGDPdef) π dCPI	0.29 0.33	1.29	1.09	15.50	1.07	20.74	0.14 0.28	-0.28	-0.31	-0.26	-0.31
TFP	0.81	1.34	1.11	17.16	1.12	34.88	0.58	0.55	0.73	0.36	0.73
							contemp. corr. with nom. interest rates [$\tilde{R}$(M2)/$\tilde{R}^{corp}$]				
TFP							−0.29 −0.44	-0.53	0.15	-0.74	0.12
							contemp. corr. with inflation [π (dGDPdef)/π (dCPI)]				
TFP							−0.35 −0.22	0.01	-0.27	-0.02	-0.27

1) Percentage change due to shutting down money shocks in benchmark economy (column two vs. column three).

2) Percentage change due to shutting down money shocks in economy with $\theta = 0.05$ (not reported vs. column five).

All series except nominal interest rates and inflation are in logs. All series have been Hodrick-Prescott filtered with a smoothing parameter of 1600. Empirical statistics are based on US quarterly data 1964:1-2006:2. Nominal interest rates are measured by the own rate on $M2$ ($\tilde{R}\,(M2)$) and the yield on corporate bonds (Moody's Seasoned Aaa Corporate Bond Yield) ($\tilde{R}^{corp}$), inflation by changes in the GDP deflator ($\pi\,(dGDPdef)$) and the consumer price index ($\pi\,(dCPI)$), respectively, monetary aggregates by $M2$. Note that the model economy does not distinguish neither between $\tilde{R}\,(M2)$ and $\tilde{R}^{corp}$ nor between ($\pi\,(dGDPdef)$) and ($\pi\,(dCPI)$).

Table 3.6: Steady state values and selected contemporaneous correlations

Variable	Friedman rule $\pi^* = -2.42$	$mg^* = (1+\gamma)$ $\pi^* = 0.00$	$mg^* = 1.0167$ $\pi^* = 1.31$	$mg^* = 1.05$ $\pi^* = 4.74$	$mg^* = 1.1$ $\pi^* = 10.11$	$mg^* = 1.2$ $\pi^* = 21.69$
$\tilde{R} - 1$	0.0000	0.0248	0.0383	0.0734	0.1284	0.2471
z/k	0.1450	0.1413	0.1393	0.1344	0.1271	0.1132
d	0.0359	0.0336	0.0325	0.0297	0.0260	0.0197
d/y	0.0921	0.0897	0.0887	0.0857	0.0815	0.0730
$d/(d + \theta wL)$	0.3700	0.3658	0.3637	0.3578	0.3497	0.3314
G	0.8414	0.8330	0.8285	0.8165	0.7975	0.7563
y^z/y^k	0.1537	0.1483	0.1455	0.1381	0.1276	0.1077
$\mathcal{T}$	0.9712	0.9672	0.9650	0.9593	0.9506	0.9321
$\rho(\tilde{R}, \mathcal{T})$	-0.49	-0.52	-0.53	-0.55	-0.57	-0.61

Statistics generated from simulated and Hodrick-Prescott filtered (smoothing parameter 1600) series for the benchmark economy.

Table 3.7: USA: Sectoral volatility and mean of growth in value added

Industries	volatility	ranking	average growth	ranking
Petroleum refineries	22.41135418	1	8.718858009	4
Non-ferrous metals	14.82056985	2	6.70920077	14
Iron and Steel	13.20761732	3	4.28101271	26
Wood products, except furniture	12.33161156	4	7.080945619	13
Professional & scientific equipment	11.82739193	5	9.520253349	3
Leather products	10.80728372	6	3.355740195	28
Industrial chemicals	9.80919931	7	6.565964224	17
Tobacco	9.466520079	8	9.765847611	2
Plastic products	9.047342577	9	11.40471846	1
Misc. petroleum and coal products	8.966026705	10	7.523389904	8
Transport equipment	8.93003486	11	6.708187212	15
Pottery, china, earthenware	8.753001453	12	6.344808742	18
Machinery, except electrical	8.447901686	13	7.217618028	11
Footwear, except rubber or plastic	7.94506906	14	0.592402327	29
Machinery, electric	7.771043776	15	7.865959786	6
Furniture, except metal	7.139279992	16	7.311662001	10
Paper and products	7.022639071	17	7.458034007	9
Other non-metallic mineral products	6.880040345	18	5.97226836	23
Textiles	6.602291836	19	5.229363677	25
Rubber products	6.212744352	20	5.399295643	24
Other manufacturing products	5.895932472	21	6.204043301	20
Glass and products	5.803579219	22	6.009918041	22
Wearing apparel, except footwear	5.515015898	23	3.865111854	27
Fabricated metal products	5.513984278	24	6.108224644	21
Total manufacturing	5.035217269	25	7.183158099	12
Printing and publishing	4.634205085	26	8.18032749	5
Beverages	4.122690753	27	6.238331092	19
Other chemicals	3.660652642	28	7.535671621	7
Food products	2.840748937	29	6.661717672	16

Table 3.8: US sectoral yearly data:
Inflation-sensitivity with respect to volatility and mean of growth rate of value added

	Growth rate of value added						
	full sample	vol>med	vol<med	full sample	full sample	full sample	full sample
inflation	-.9632***	-1.19**	-.7390***	-.8014***	-.8107***	-.8700***	-1.02***
	(-4.20)	(-2.69)	(-5.83)	(-3.84)	(-3.73)	(-3.51)	(-4.25)
infl∗dvol				-.3235*	-.6167**		
				(-1.65)	(-2.58)		
infl∗dmean						-.1981	.2379
						(-.97)	(1.14)
GDP-growth	1.20***	1.29**	1.10***	1.19***	1.19***	1.20***	1.19***
	(4.36)	(2.67)	(3.92)	(4.36)	(4.34)	(4.36)	(4.35)
L.GDP-growth	-.7851***	-.8938*	-.6764***	-.7851***	-.7869***	-.7839***	-.7858***
	(-2.92)	(-1.71)	(-4.11)	(-2.92)	(-2.93)	(-2.92)	(-2.92)
credit	-11.46***	-15.01**	-7.91***	-11.46***	-11.52***	-11.42***	-11.49***
	(-3.26)	(-2.23)	(3.86)	(-3.26)	(3.27)	(3.52)	(-3.27)
inv-share	.5734**	.8181	.3287	-.6305	.5734**	.5720**	.5741**
	(2.04)	(1.55)	(1.64)	(2.04)	(2.05)	(2.03)	(2.04)
Ind./Obs.	28/946	14/473	14/473	28/946	28/946	28/946	28/946

The correlation coefficient between the volatility- and mean rankings amounts to 0.23 (s.e. 0.03) according to Spearman's rank correlation test.

1963-2000 yearly data. Always include a constant. Heteroscedasticity- and serial correlation robust s.e.

t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.

Table 3.9: US firm-level quarterly data: Inflation, liquidity-holdings & R&D expenses

	Corporate liquidity		R&D expenses per firm				
	GMM-sys	GMM-sys	GMM-sys	GMM-sys[1)]	GMM-sys	GMM-sys[1)]	GMM-sys
inflation	-1.06		-.8556**	-.4257			-11.74***
	(-1.10)		(-2.08)	(-1.01)			(-2.81)
yield-corp-bonds		-1.38**			-.5967***	-.3137	
		(-2.20)			(-2.77)	(-1.51)	
corp. liquidity				.0383***		.0382***	
				(2.73)		(2.73)	
assets	.0138***	.0138***	.0129***	.0091***	.0129***	.0091***	.0015***
	(3.62)	(3.62)	(8.89)	(5.01)	(8.90)	(5.01)	(6.06)
spdrc							-1.65
							(-.79)
lag-dep.-var.	.9013***	.9012***	-.0576	-.0783	-.0578	-.0785	-.0728**
	(14.77)	(14.75)	(-1.39)	(-1.02)	(-1.39)	(-1.02)	(-1.94)
Firms	5892	5892	6052	6052	6052	6052	425
Observations	115811	115811	121106	120730	121106	120730	7482
1. auto-cor.	.998	.008	.012	.018	.012	.018	.007
2. auto-cor.	.110	.110	.211	.140	.111	.140	.162
Hansen-test	.464	.480	.125	.246	.113	.239	.697

1) The IV-matrix starts at the 4. lag since Hansen-test indicates that 2. and 3. lag endogenous.

Firm-level data on R&D expenses, corporate liquidity and total assets all measured in millions of US$.

1989:1-2000:4 quarterly data. Heteroscedasticity- and serial correlation robust s.e. t-statistics in parenthesis.

***,**,* significant at 1%, 5%, 10%.

Table 3.10: US firm-level yearly data: Inflation, liquidity holdings and R&D expenses

	Corporate liquidity		R&D expenses per firm				*spdrc* < 12	*spdrc* ≥ 12
	GMM-sys	GMM-sys	GMM-dif	GMM-dif	GMM-sys	GMM-sys1)	GMM-sys	GMM-sys
inflation	-1.38**		-.4707*	-.3764*			-3.721*	-22.514**
	(-2.32)		(-1.73)	(-1.68)			(-1.72)	(-2.16)
yield-corp-bonds		-1.61**			-.0366	.0889		
		(-2.34)			(-.34)	(.88)		
corp. liquidity				.0353***		.0486***		
				(4.15)		(4.20)		
assets	.0230**	.0231**	.0035**	.0021	.0007	-.0010	-.0014	-.0008
	(2.23)	(2.25)	(2.18)	(1.48)	(-1.19)	(-1.57)	(-.74)	(-.24)
spdrc							-99.1	-439.3**
							(-1.24)	(-2.09)
lag-dep.-var.	.7361***	.7357***	.8504	.8237	1.01	.9462	.1.00	.9289
	(7.73)	(7.77)	(19.08)	(17.73)	(29.43)	(21.00)	(14.69)	(7.52)
Firms	10903	10923	9705	9703	9742	10925	378	492
Observations	83468	84277	72009	71981	84355	84314	6217	5194
1. auto-cor.	.002	.002	.001	.002	.001	.001	.017	.182
2. auto-cor.	.468	.488	.604	.554	.616	.533	.519	.474
Hansen-test	.238	.260	-	-	.075	.267	221	.274

1) The IV-matrix starts at the 4. lag since Hansen-test indicates that 2. and 3. lag endogenous.

Firm-level data on R&D expenses, corporate liquidity and total assets all measured in millions of US$.

1970-2000 yearly data. Heteroscedasticity- and serial correlation robust s.e. t-statistics in parenthesis.

***,**,* significant at 1%, 5%, 10%.

Concluding Remarks

This dissertation contains three essays on monetary policy interactions with fiscal policy and financial markets. The main theoretical and empirical results of this endeavor have been summarized within the individual chapters. To conclude, it is therefore useful to put the thesis as a whole into perspective. For that purpose, it seems appropriate to briefly point out a number of limitations of the present dissertation and, starting from there, to indicate directions for future research.

Importantly, the preceeding three chapters have been exclusively concerned with closed economies, leaving aside many interesting open economy considerations. These, in turn, are crucial in the context of the problem of international macroeconomic policy coordination. The policy interaction framework laid out in the first two chapters of this thesis is a natural one to investigate such questions, particularly when domestic and international frictions or incentive problems interact in a non-trivial way.[55] Against this background, a limitation of the bulk of the existing literature on international policy coordination is that it abstracts from dynamics in endogenous state variables such as capital stocks and net foreign asset portfolios. Chapters one and two have illustrated the role of one such endogenous state variable, the real value of outstanding government debt, in shaping the incentives faced by sequential policy makers, but due to the focus on a closed economy, the composition of the asset portfolios in terms of domestic versus foreign bonds held by private agents was not an issue. In an international setup, however, agents can endogenously choose their portfolios in view of the relevant assets' payoffs and their covariance characteristics with national policies and shocks. This adds another dimension to both the determination of a competitive equilibrium for given government policies and to the problem of implementing optimal policies taking into account this endogenous portfolio choice.[56] In terms of both normative results and

[55] Rogoff (1985a) shows that the international coordination of monetary policy may be counterproductive because it aggravates domestic credibility problems; Kehoe (1989) establishes the same result for fiscal policies; conversely, in highlighting policy makers' incentives to manipulate the terms of trade, Cooley and Quadrini (2003) argue that giving up monetary independence may be welfare improving despite the loss of country-specific stabilization instruments.

[56] Compare Smith (1995) for some empirical evidence as well as Cooper, Kempf and Peled (2004) and Devereux and Sutherland (2007) for partial analyses along these lines.

positive predictions, it would therefore be interesting to learn what an optimal taxation approach implies for international risk sharing, asset portfolio dynamics and other issues in international finance.

Returning to a closed economy framework, given that the analysis in chapters one and two has been confined to a relatively rudimentary deterministic environment, it is desirable to study the dynamic interaction between monetary and fiscal policy makers in empirically more plausible setups. These would allow for capital accumulation, imperfect competition on goods and factor markets, nominal rigidities as well as uncertainty deriving from a set of stochastic shocks. In such a framework, little is known about optimal time consistent (as opposed to Ramsey) policies in general and about the implications of decentralizing decision authority to interacting authorities in particular. Thus, the analysis of the cyclical properties of key macroeconomic variables like government debt and inflation induced via the sequential choice of monetary and fiscal policy instruments is an open task.

On different grounds, we notice that chapter three addresses a particular financial market imperfection, but does neither attempt to provide a comprehensive account along this dimension nor touch upon frictions prevailing in other important markets such as the labor market. Certainly, labor market frictions are an important determinant of an economy's aggregate productivity. Hence, a better understanding of the joint implications of these frictions and the conduct of macroeconomic policies for economic performance is critical, particularly if imperfections catalyze spillovers between financial and labor markets.[57] Another simplification in the modelling approach taken in chapter three has been to boil down the implications of heterogeneity across entrepreneurial firms. In the presence of financial frictions, firm characteristics such as net worth are an important determinant of corporate activity. In considering a sequence of period-by-period financial contracts rather than a dynamic specification of the contracting problem, chapter three has largely abstracted from the effects of monetary policy on the dynamics among heterogenous, financially constrained firms. Cooley and Quadrini (2006) present a model featuring such dynamic interactions between monetary policy, financial contracting and firm dynamics, which could provide a valuable starting point for thinking about the effects of monetary policy on firms' financial structure, their accumulation decisions with respect to technology-specific capital and their capacity utilization. In this context, the empirical part of this thesis has offered only a very superficial analysis of the monetary transmission mechanism and of other salient business cycle phenomena and thus made only a marginal contribution to this branch of the literature; elaborating along this dimension, e.g. by means of vector autoregressions, would therefore be desirable.

There is no doubt that these ignored issues constitute important and interesting

[57]This latter aspect has been stressed e.g. in Wasmer and Weil (2004).

avenues for future research. Nevertheless, at this stage, rather than enumerating further potential extensions, it seems more fruitful to hint at a set of connections which link the seemingly disjoint questions underlying the first two versus the third chapter of this dissertation. Chapters one and two emphasize a time consistency problem for monetary policy in the presence of nominal government debt. In this environment, the mechanics are such that the incentives faced by the policy maker to improve upon the second best allocation render the Ramsey equilibrium unattainable and lead to a third best outcome. It turns out that the model in chapter three allows for very similar effects as soon as monetary policy is endogenized. Indeed, given the result established there that monetary policy is non-neutral with respect to aggregate productivity, it is natural to ask the following question: Can a cyclically responsive policy, which provides additional liquidity when production via the advanced technology is particularly valuable, successfully stabilize the economy? In other words, what are the implications of the monetary authority adopting an active liquidity management policy? The results (not reported here) emerging from the model simulation under an exogenously stipulated active liquidity management policy indicate that there are hazards attached to such a policy in that (i) the composition of aggregate activity is inferior than absent active liquidity management, and that (ii) the volatility of macroeconomic aggregates is increased. These findings are most straightforwardly understood as resulting from the following mechanism which propagates a shock to the relative attractiveness of producing by means of the advanced technology, say a positive one: Under an active liquidity management regime, monetary policy should react by a money injection. On impact, this expansion generates a liquidity effect which indeed facilitates better insurance of production via the advanced technology. However, due to the systematic reaction of monetary policy, the autocorrelation in the technology-specific shocks induces a corresponding autocorrelation also in money growth rates; hence, rational expectations dictate an increase in the following periods' nominal interest rates. This, in turn, triggers an adverse investment composition effect and also a poorer insurance of advanced production projects. As hinted above, the overall effect is an inferior composition of aggregate activity, combined with an increase in the realized volatility of macroeconomic aggregates.

Taking this idea one step further requires making monetary policy truly endogenous in the sense of deriving monetary policy actions as resulting from an explicit dynamic optimization problem. Against the background of the findings for the exogenous active liquidity management regime, we conjecture that, under optimal monetary policy without commitment, there is scope for expectation traps: The policy maker's incentive to improve the allocation by providing additional liquidity is anticipated by the private agents, which induces them to shift their physical investment and financial asset portfolios towards basic technologies and non-intermediated cash balances, respectively. This adverse constellation, in turn, makes the anticipated monetary expansion indeed a best response on behalf of the policy maker and may give rise to multiple fixed points between private expectations and optimal policies, conditional on these expectations. Then, besides a low inflation equilibrium with a favorable investment composition, there would exist a high inflation equilibrium with a poor investment composition and low aggregate productivity.[58] This multiple equilibria framework facilitates to formally think about a number of interesting empirical phenomena, especially if the composition of past investments has an effect on the evolution of aggregate productivity, as stressed in the endogenous growth model in Evers, Niemann and Schiffbauer (2007).

Finally, the (potential) importance of government debt constitutes another nexus between the individual chapters of this dissertation. While this is explicit in the strategic optimal taxation setup of the first two chapters where a measure of the real value of public liabilities is the key state variable, government-issued bonds can also play a central role as a means of providing and managing aggregate liquidity in the context of the economy outlined in the third chapter. Basically, government debt can fulfill the function of insuring advanced production in a similar way as liquidity in the form of intermediated money.[59] One objective then would be to meaningfully distinguish between money and bonds as instruments for liquidity provision; an interesting question concerns the substitution between money and (short-term) bonds over the business cycle and particularly in the context of monetary policy operations. Again, two recurring characteristics of government debt are important here: First, even though nominal government bonds are not generally issued as explicitly state contingent, their returns can be made state contingent in real terms via manipulation of the price level. Second, while inflation may therefore be a way to manage aggregate liquidity, the fiscal dimension of government debt is likely to bring time consistency problems back to the stage; the induced distortions in nominal interest

[58]This is reminiscent of the findings in Albanesi, Chari and Kehoe (2003). Notice also that the low inflation equilibrium would be characterized by a liquidity trap in the sense that financial markets do not absorb additional liquidity, thus leaving intact the policy maker's incentive to abstain from a monetary expansion.

[59]The role of public debt as private liquidity for consumption and investment problems is addressed in Woodford (1990). Against this background, Holmström and Tirole (1998) are concerned with the following agenda: First, do private markets offer sufficient insurance opportunities, or will the government have a role to play? Rephrased in terms of liquidity: Do private claims on real investments supply enough liquidity, or can the government enhance liquidity by issuing its own securities? Second, if so, then how should the government manage aggregate liquidity? The answer to the first question is that, under incomplete markets, the presence of securities issued by the government can generally improve upon the competitive equilibrium allocation available to the private sector on its own. The reason for this lies in the fact that, because of its right to levy non-financial penalties and to collect taxes, the government can create assets which the private sector cannot replicate due to information or incentive problems. The answer to the last question very much depends on the assumptions regarding the government's access to information and commitment.

rates would then also impinge on the liquidity premium. These issues are also of interest from the perspective of a corporate finance-based approach to asset pricing.[60] The key mechansim there is a feedback from the supply of assets to real allocations, which makes asset prices become sensitive to the supply of liquidity by the corporate sector and the government. Within this environment, an interesting observation is that the price of government bonds does not only command a risk premium, but also a liquidity premium. Hence, liquidity-constrained models might constitute a valuable framework to explain both the non-neutrality of government deficits over short and long horizons and the equity premium puzzle, i.e. the persistently low returns on bonds relative to other assets.

[60] Holmström and Tirole (2001) provide a model along these lines, advocating a liquidity-based concept with supply-side mechanisms in the productive sector to complement the traditional consumption-based asset pricing models.

Appendix A

Appendix to Chapter 1

A.1 Some notation

The aggregate state is $z^g \equiv \frac{B^g(1+R)}{M^g}$; in the rational expectations equilibrium, the representative household's state z and the aggregate state z^g coincide, so in what follows the supersript g is dropped. The current policy rule, which consists of a fiscal and a monetary rule for the present period, is $\pi(z) = (\pi_f(z), \pi_m(z))$. The future policy rule, which consists of a fiscal and a monetary rule from the next period onwards, is $\varphi(z) = (\varphi_f(z), \varphi_m(z))$. We abuse notation by letting the policy rules map the aggregate state either into the true policy instruments (τ^c, M') or alternatively - the primal approach - directly into the allocation (c, z').

A.2 Objective functions and implementability constraint

Making a primal approach to the dynamic game operational requires a number of substitutions which make use of the private equilibrium conditions (1.7), (1.8) and (1.9). Both authorities' value functions can be constructed directly from the allocation. The authorities' preferences over allocations are identical; however, due to the different dynamic constraints faced by them, we have to distinguish between two distinct value functions. It is convenient to start from the problem faced by the authorities when they assume that (i) the policy rule φ will govern the play from the next period onwards and that (ii) the current policy choice by the respective opponent (in terms of the true policy instrument) is π_{-i}. Then, for the fiscal authority, we have:

$$\hat{V}(z; \pi, \varphi) = max_{\pi_f}\{[log(c) - \alpha(c+g)] + \beta V(z'; \varphi)\}$$

For the monetary authority, one obtains:

$$\hat{W}(z;\pi,\varphi) = max_{\pi_m}\{[log(c) - \alpha(c+g)] + \beta W(z';\varphi)\}$$

For these value functions to make sense, they must be amended by the appropriate dynamic constraints. In their respective maximization problems, both authorities are constrained by a sequence of implementability constraints which internalize the fact that the private households react optimally to the government policies. We construct these implementability constraints by substituting the private equilibrium conditions (1.7), (1.8) and (1.9) into the consoldiated government budget constraint (1.1). A complication which arises as a consequence of decision authority over policies being decentralized is that each authority's constraint depends on the policy implemented by its contemporaneous opponent. This problem is taken care of via the consistency condition (1.15) which is constructed from the private sector optimality conditions (1.8) and (1.9) together with the CIA constraints (1.7) for two adjacent periods:

$$c(1+\tau^c)\frac{M'}{M} = c(1+\tau^c)(1+\mu) = \frac{\beta}{\alpha},$$

where the first equality simply employs the definition $(1+\mu) \equiv \frac{M'}{M}$. Making use of above consistency condition, the substitution of the private equilibrium conditions into the consolidated government budget constraint yields two distinct implementability constraints. For the fiscal authority, we have:

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'}{(1+\mu(z'))} - c - \frac{\beta}{\alpha}\frac{z}{(1+\mu)} = 0 \tag{A.1}$$

For the monetary authority, we have:

$$\frac{\beta}{\alpha} - g + \beta z'c(z')(1+\tau^c(z')) - c - zc(1+\tau^c) = 0 \tag{A.2}$$

Note that in both cases the implementability constraint's job is twofold: First, for a given value of the policy instrument chosen by the other authority, it imposes a joint restriction on compatible choices of c and z'; secondly, since the feasible set is contingent on the policy instrument chosen by the other authority, it establishes a one-to-one mapping between the own policy instrument and the implemented allocation (c, z'). However, note that there is an asymmetry in the two equations: In the implementability constraint (A.1) faced by the fiscal authority, the choice variable c appears without cofactor; in contrast, in the monetary authority's implementability constraint (A.2), it is scaled up by the cofactor $[1 + z(1+\tau^c)]$. This reflects the fact that the fiscal authority's current policy choice has no direct influence on the contemporaneous price level P, whereas monetary policy, by manipulating the price level, can also affect the real value of the outstanding stock of government liabilities.

A.3 Existence of Markov-perfect equilibrium

A.3.1 Preliminaries

We define the following two subsets of $C(I)$, the Banach space of bounded continuous functions defined on a compact subset $I \subset \mathcal{R}$:

1. The effective strategy space of stationary Markov strategies (policy functions) for the two players $i = f, m$ mapping the current state into the space of admissible actions $A_i = [a^i_{min}, a^i_{max}]$:

$$LCM_{K_i} \equiv \{\varphi_i : I \to [a^i_{min}, a^i_{max}], \forall z_1, z_2 \in I, z_1 \leq z_2 \quad \text{have}$$
$$0 \leq \varphi_i(z_2) - \varphi_i(z_1) \leq K_i(z_2 - z_1) \quad \text{for some finite} \quad K_i \in \mathcal{R}_+\}$$

   This is the familiy of uniformly Lipschitz-continuous monotone nondecreasing functions; since this set of functions is closed, bounded and equicontinuous, by the Arzela-Ascoli theorem LCM_{K_i} is a compact subset of $C(I)$.

2. The corresponding space of value functions when the players $i = f, m$ use strategies in LCM_{K_i}:

$$CM^i \equiv \{v : I \to \mathcal{R},\ v \text{ continuous and nonincreasing}\}$$

   This is the family of continuous, monotone nonincreasing, bounded functions; under the sup-metric $d(f, g) = sup_{x \in I}|f(x) - g(x)|$ induced by the supremum norm, CM^i is a closed subset of $C(I)$ and thus a complete metric space.

Moreover, a couple of preliminary results are made use of. Specifically, considering the consistency condition (1.15):

$$c(1 + \tau^c)\frac{M'}{M} = c(1 + \tau^c)(1 + \mu) = \frac{\beta}{\alpha}$$

and recalling the restrictions $\tau^c_{min}(z) > -1$ and $M'_{min}(z) > 0$ on the admissible actions, the following results can be inferred:

- From the consistency condition (1.15), given a monetary policy function $M'(z) \in LCM_{K_m}$, c is continuous and nonincreasing in τ^c. Since M' is bounded away from 0 and τ^c is bounded away from -1, conditional on some $M'(z) \in LCM_{K_m}$ we have:

$$\left|\frac{\partial c}{\partial \tau^c}\right| = \left|-\frac{\beta}{\alpha}\frac{M}{M'}\frac{1}{(1 + \tau^c)^2}\right| < \infty,$$

  i.e. c is Lipschitz-continuous in τ^c. It is now immediate to verify that, conditional on a monetary policy function $M'(z) \in LCM_{K_m}$, $c(\tau^c)(1 + \tau^c)$

is Lipschitz-continuous in τ^c. Using this last result in (1.15), given that $M'(z) \in LCM_{K_m}$, it follows that $c(\tau^c)(1+\tau^c)$ must be Lipschitz-continuous in z. Finally, since c is Lipschitz-continuous in τ^c, τ^c itself must be Lipschitz-continuous in z. For future reference, we define $K(z) \equiv c(\tau^c(z))(1+\tau^c(z))$.

- From the consistency condition (1.15), given a fiscal policy function $\tau^c(z) \in LCM_{K_f}$, c is continuous and nonincreasing in M'. Since M' is bounded away from 0 and τ^c is bounded away from -1, conditional on some $\tau^c(z) \in LCM_{K_f}$ we have:

$$\left|\frac{\partial c}{\partial M'}\right| = \left|-\frac{\beta}{\alpha}\frac{1}{(1+\tau^c)}\frac{M}{(M')^2}\right| < \infty,$$

  i.e. c is Lipschitz-continuous in M'. It is now immediate to verify that, conditional on a fiscal policy function $\tau^c(z) \in LCM_{K_f}$, $c(M')M'$ is Lipschitz-continuous in M'. Using this last result in (1.15), given that $\tau^c(z) \in LCM_{K_f}$, it follows that $c(M')M'$ must be Lipschitz-continuous in z. Finally, since c is Lipschitz-continuous in M', M' itself must be Lipschitz-continuous in z. Since M is a given constant and M' is bounded away from 0, also $\frac{1}{(1+\mu)} = \frac{1}{M'/M}$ must be Lipschitz-continuous in z. For future reference, we define $H(z) \equiv \frac{1}{(1+\mu(z))}$.

- From the consistency condition (1.15), it follows that $K(z)$ and $H(z)$ must obey the same Lipschitz constant.

A.3.2 Proof

The proof is adapted from Amir (1996) and delivers an existence result based on the following structure. The *first step* (Lemmata A.4, A.5) is to postulate a particular conjecture that player $i = f, m$ holds about its respective opponent's play. In particular, the conjectures are chosen such as to guarantee the concavity of the relevant optimization problems. The *next step* (Lemmata A.8, A.9) is to infer the properties of the players' best responses derived on the basis of their conjectures about the other one's play and to verify that the derived best responses and the conjectures that induce them are mutually consistent. Hence, the system of conjectures and best responses constitutes a Nash equilibrium. Existence of such an equilibrium is established via the Schauder fixed point theorem. The following proposition simply restates Proposition 1.1 from the main text and further characterizes the equilibrium strategies.

Proposition A.1 *The infinite-horizon game has a (differentiable) Markov-perfect equilibrium in stationary strategies. These strategies are elements of* $LCM_{K_f} \times LCM_{K_m}$.

To prove the proposition, we begin with the following auxiliary Lemma:

Lemma A.1 *Let $f_n, f : I \to \mathcal{R}$. If f_n converges uniformly to f on any compact subset of I, $x_n \in \arg\max f_n$ and x is a limit point of $\{x_n\}$, the subsequence $\{x_m\}$ being convergent to x, then:*

$$f(x) = \sup f = lim_{m\to\infty}(\sup f_m).$$

Proof: See Kall (1986).

We can now establish the following Lemmata:

Lemma A.2 *In the optimization problem for the fiscal authority, if the monetary authority uses a stationary strategy $h \in LCM_{K_m}$ such that $zH(z)$ nondecreasing, then $V_h \in CM^f$ and V_h is the unique solution to the functional equation:*

$$\begin{aligned} V_h(z) &= max_{\tau^c}\{log(c(\tau^c)) - \alpha(c(\tau^c)+g) + \beta V_h(z') \\ s.t. \quad & \frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}z'H(z') - c(\tau^c) - \frac{\beta}{\alpha}zH(z) = 0\} \end{aligned} \tag{A.3}$$

Proof: Define the map $T : CM^f \to CM^f$ by:

$$\begin{aligned} T(v)(z) &= \sup\{log(c(\tau^c)) - \alpha(c(\tau^c)+g) + \beta v(z') \\ \text{s.t.} \quad & z'H(z') = \frac{c(\tau^c) + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}}\} \end{aligned} \tag{A.4}$$

First, we show that T indeed maps CM^f into itself. To this end, we start by proving that the supremand in (A.4) is continuous in (z, τ^c). Let $z_n \to z$ and $\tau^c_n \to \tau^c$ and note from above result that, given $h(z) \in LCM_{K_m}$, we have (i) that $z_nH(z_n) \to zH(z)$ and (ii) that $c(\tau^c)$ is continuous in τ^c. Hence, the RHS of the constraint set is continuous in (z, τ^c); it follows that $z'_nH(z'_n) \to z'H(z')$. Since $H(z')$ is continuous in z', we have $z'_n \to z'$; and since $v \in CM^f$, $v(z'_n) \to v(z')$. The feasible set for τ^c, A_f, is a continuous correspondence that is nonempty and compact. Hence, by the theorem of the maximum, $T(v)$ is continuous. Next, we show that $T(v)$ is nonincreasing. Let $z_2 \geq z_1$. Then, for any given τ^c, since $zH(z)$ is nondecreasing, we have $z'_2 \geq z'_1$, where z'_n solves $z'_nH(z'_n) = \frac{c(\tau^c)+\frac{\beta}{\alpha}z_nH(z_n)+g-\frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}}$, $n = 1, 2$. Thus, since $v \in CM^f$:

$$log(c(\tau^c)) - \alpha(c(\tau^c)+g) + \beta v(z'_1) \geq log(c(\tau^c)) - \alpha(c(\tau^c)+g) + \beta v(z'_2)$$

Since $T(v)(z_1)$ is the sup of the LHS over $\tau^c \in A_f(z_1)$, $T(v)(z_2)$ is the sup of the RHS over $\tau^c \in A_f(z_2)$, and since $A_f(z_2) \subset A_f(z_1)$, we have $T(v)(z_1) \geq T(v)(z_2)$, i.e. $T(v)$ is nonincreasing. Hence, T maps CM^f into itself. Since CM^f is a complete metric space, it is now easy to verify that T is a contraction with a unique fixed point $V_h \in CM^f$ that satisfies (A.3).

Lemma A.3 *In the optimization problem for the monetary authority, if the fiscal authority uses a stationary strategy $k \in LCM_{K_f}$ such that $zK(z)$ nondecreasing, then $W_k \in CM^m$ and W_k is the unique solution to the functional equation:*

$$
\begin{aligned}
& W_k(z) = max_{M'}\{log(c(M')) - \alpha(c(M') + g) + \beta W_k(z') \\
& s.t. \qquad z'K(z') = \frac{c(M') + zc(M')(1 + \tau^c(z)) + g - \frac{\beta}{\alpha}}{\beta}\}
\end{aligned}
\tag{A.5}
$$

Proof: As for Lemma A.2.

We now establish that, if each of the two authorities has an appropriate conjecture about its respective opponent's play, then the value functions derived on the basis of these conjectures are strictly concave. The detour involving specific conjectures about the other player's strategy is needed because in general deterministic games with simultaneous moves, the players' best response optimization problems may fail to be concave due to the presence of the other player's strategy that has to be taken into account. Under appropriate conjectures, the simultaneity of moves does not introduce such non-concavities. Later, Lemmata A.8, A.9 will establish that the assumed conjectures are consistent with the actual play.

Lemma A.4 *If the fiscal authority has a conjecture about the play h of the sequence of monetary authorities such that $zH(z)$ nondecreasing and convex, then the fiscal value function V_h is strictly concave.*

Proof: Conditional on some conjecture h, the fiscal authority faces a problem with solution (A.3). In this problem, the state space I is convex, the constraint set $\Gamma(z) = \{c : \bar{Z}H(\bar{Z}) \geq z'H(z') = \frac{c + \frac{\beta}{\alpha} zH(z) + g - \frac{\beta}{\alpha}}{\beta \frac{\beta}{\alpha}}\}$ is non-empty, compact-valued and continuous, and the period return $log(c) - \alpha(c + g)$ is strictly concave in c. Now, we show that, if the fiscal authority has a conjecture h that stipulates $zH(z)$ nondecreasing and convex, then $\Gamma(z)$ is convex. Let $c_n \in \Gamma(z_n)$ attain $T(v)(z_n)$ in (A.4), $n = 1, 2$; let $z_\theta = \theta z_1 + (1 - \theta)z_2$. Then, one can easily verify that $c_\theta = \theta c_1 + (1 - \theta)c_2 \in \Gamma(z_\theta)$ if $zH(z)$ is nondecreasing and convex. That is, $\Gamma(z)$ is convex if $zH(z)$ is nondecreasing and convex. Having established the convexity of $\Gamma(z)$, all assumptions of Theorem 4.8 in Stokey and Lucas (1989) are satisfied, and the strict concavity of V_h follows.

Lemma A.5 *If the monetary authority has a conjecture about the play k of the sequence of fiscal authorities such that (i) $z(1 + \tau^c(z))$ is nondecreasing and (ii) $zK(z)$ is nondecreasing and convex, then the monetary value function W_k is strictly concave.*

Proof: As for Lemma A.4.

Lemma A.6 *Under the assumptions of Lemma A.4, if the monetary authority uses a stationary strategy $h \in LCM_{K_m}$, then there is a unique stationary best response k by the fiscal authority.*

Proof: We show that for any $z \in I$ the maximand in (A.3) is a strictly concave function of $c(\tau^c)$. It is easy to verify that the first term, $log(c(\tau^c)) - \alpha(c(\tau^c) + g)$, is strictly concave in c. As to the second term, fix any feasible c_1, c_2 and $\lambda \in [0,1]$ and observe:

$$\lambda V_h\left(\frac{c_1 + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H(z_1')}\right) + (1-\lambda)V_h\left(\frac{c_2 + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H(z_2')}\right)$$
$$\leq V_h\left(\lambda\frac{c_1 + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H(z_1')} + (1-\lambda)\frac{c_2 + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H(z_2')}\right),$$

where the weak inequality follows from the fact that, under the conditions of Lemma A.4, V_h is concave. Since for any given z and stationary $h(z) \in LCM_{K_m}$, the feasible set $\Gamma(z)$ for c is convex and (by the compactness of the set of admissible choices τ^c) compact, there is a unique argmax (in terms of c) for (A.3). From the consistency condition (1.15), for a given $M'(z)$, there is a one-to-one mapping between c and τ^c; hence, the result carries over to τ^c and we have a unique stationary best response by the fiscal authority.

Lemma A.7 *Under the assumptions of Lemma A.5, if the fiscal authority uses a stationary strategy $k \in LCM_{K_f}$, then there is a unique stationary best response h by the monetary authority.*

Proof: As for Lemma A.6.

Lemma A.8 *Under the assumptions of Lemma A.4, if the monetary strategy is a stationary $h \in LCM_{K_m}$, then the fiscal authority's unique stationary best response k, which gives τ^c as a function of the state z, is in LCM_{K_f}. Moreover, k is such that (i) $z(1 + \tau^c(z))$ is nondecreasing and (ii) $zK(z)$ is nondecreasing and convex.*

Proof: From Lemma A.6, we know that k is single-valued. First, we show that k is nondecreasing. To this end, we establish two auxiliary results: (i) the set $L = \{(zH(z), \tau^c) : zH(z) \leq \bar{Z}H(\bar{Z}), \tau^c \in \tilde{A}_f(zH(z)) = [\tau^c_{min}(zH(z)), \tau^c_{max}(zH(z))]\}$ is a lattice; and (ii) V_h is supermodular on L; compare e.g. Vives (1999).

To establish (i), it is sufficient to note that $\tau^c_{min}(z)$ and $\tau^c_{max}(z)$ are both nondecreasing in z and, since $zH(z)$ is nondecreasing in z, also in $zH(z)$. The fact that L is a lattice follows immediately.

To establish (ii), we show the equivalent result that V_h has nondecreasing differences in $(zH(z), \tau^c) \in L$ and start from the result (Lemma A.4) that V_h is concave.

Fix $z_2 \geq z_1$ and $\tau_2^c \geq \tau_1^c$ with $\tau_{min}^c(z_n) \leq \tau_n^c \leq \tau_{max}^c(z_n)$, $n = 1, 2$. Define z'_{ab} to be the solution to $z'_{ab}H(z'_{ab}) = \frac{c(\tau_a^c)+\frac{\beta}{\alpha}z_b H(z_b)+g-\frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}}$. From the fact that $c(\tau^c)$ is decreasing in τ^c and $zH(z)$ is nondecreasing in z, it then follows that:

$$z'_{12}H(z'_{12}) \geq z'_{nn}H(z'_{nn}) \geq z'_{21}H(z'_{21}),$$

where the sum of the two outer terms is equal to the sum of the two inner terms. Hence, there exists λ with $0 \leq \lambda \leq 1$ such that:

$$z'_{11}H(z'_{11}) = \lambda z'_{12}H(z'_{12}) + (1-\lambda)z'_{21}H(z'_{21})$$

and:

$$z'_{22}H(z'_{22}) = (1-\lambda)z'_{12}H(z'_{12}) + \lambda z'_{21}H(z'_{21})$$

Now, using the concavity of V_h on the two expression above, we have:

$$\begin{aligned} & V_h\left(z'_{11}H(z'_{11})\right) + V_h\left(z'_{22}H(z'_{22})\right) \\ \geq\ & \lambda V_h\left(z'_{12}H(z'_{12})\right) + (1-\lambda)V_h\left(z'_{21}H(z'_{21})\right) + (1-\lambda)V_h\left(z'_{12}H(z'_{12})\right) + \lambda V_h\left(z'_{21}H(z'_{21})\right) \\ =\ & V_h\left(z'_{12}H(z'_{12})\right) + V_h\left(z'_{21}H(z'_{21})\right), \end{aligned}$$

which implies that V_h has nondecreasing differences in $(zH(z), \tau^c) \in L$, i.e. V_h is supermodular on L.

Now, we have the following: From (i), the correspondence $zH(z) \rightarrow [\tau_{min}^c(zH(z)), \tau_{max}^c(zH(z))]$ is ascending because $\tau_{min}^c(zH(z))$ and $\tau_{max}^c(zH(z))$ are nondecreasing; from (ii), V_h is supermodular on L. Hence, by Topkis' theorem, the fiscal best response k is nondecreasing in $zH(z)$ and, since $zH(z)$ is nondecreasing in z, also in z, i.e. in case of a differentiable $\tau^c(z)$, $\frac{\partial \tau^c}{\partial z} \geq 0$. Next, we show that the slope of k must be bounded by some Lipschitz constant $K_f \in \mathcal{R}_+$. To this end, consider the consistency condition (1.15):

$$c(1+\tau^c)\frac{M'}{M} = \frac{\beta}{\alpha}$$

Here, given $M' \in LCM_{K_m}$, we have established earlier that τ^c must be Lipschitz-continuous in z. Hence, there is a finite K_f such that the fiscal best response $\tau^c \in LCM_{K_f}$. Finally, we verify that (i) $z(1+\tau^c(z))$ is nondecreasing which is an immediate implication of the fact that $\tau^c(z)$ is nondecreasing, and that (ii) $zK(z)$ is nondecreasing and convex. This last result follows from the consistency condition (1.15) which can be multiplied by z and rearranged to read $zc(\tau^c(z))(1+\tau^c(z)) = \frac{\beta}{\alpha}\frac{z}{(1+\mu(z))}$ or $zK(z) = \frac{\beta}{\alpha}zH(z)$. Here, since $zH(z)$ is nondecreasing and convex, the desired properties obtain also for $zK(z)$.

Lemma A.9 *Under the assumptions of Lemma A.5, if the fiscal strategy is a stationary* $k \in LCM_{K_f}$*, then the monetary authority's unique stationary best response* h*, which gives* M' *as a function of the state* b*, is in* LCM_{K_m}*. Moreover,* h *is such that* $zH(z)$ *is nondecreasing and convex.*

Proof: As for Lemma A.8.

Note that the properties of the fiscal best response k derived in Lemma A.8 are consistent with the supposition in Lemma A.5 about the monetary authority's conjecture with respect to the fiscal authority's play k. Similarly, the properties of the monetary best response h derived in Lemma A.9 are consistent with the supposition in Lemma A.4 about the fiscal authority's conjecture with respect to the monetary authority's play h. Hence, the system of conjectures and induced best responses is mutually consistent.

We are now ready to define the best response map BR for the infinite-horizon game. Note that, as a consequence of Lemmata A.8 and A.9, BR is single-valued. We have:

$$\begin{aligned} BR : LCM_{K_f} \times LCM_{K_m} &\rightarrow LCM_{K_f} \times LCM_{K_m} \\ (\tau^c(z), M'(z)) &\rightarrow (\tilde{\tau}^c(z), \tilde{M}'(z)), \end{aligned}$$

where:

$$V_h(z) = log(c(\tilde{\tau}^c(z))) - \alpha(c(\tilde{\tau}^c(z)) + g) + \beta V_h\left(\frac{c(\tilde{\tau}^c(z)) + \frac{\beta}{\alpha} zH(z) + g - \frac{\beta}{\alpha}}{\beta \frac{\beta}{\alpha} H(z')}\right)$$

with $H(z) \equiv \frac{1}{(1+\mu(z))}$, and:

$$W_k(b) = log(c(\tilde{M}'(b))) - \alpha(c(\tilde{M}'(b)) + g) + \beta W_k\left(\frac{c(\tilde{M}') + zc(\tilde{M}')(1 + \tau^c(z)) + g - \frac{\beta}{\alpha}}{\beta K(z')}\right)$$

with $K(z) \equiv c(\tau^c(z))(1 + \tau^c(z))$.

We endow LCM_{K_i} with the topology of uniform convergence on compact subsets of $I = [\underline{Z}, \bar{Z}]$. The resulting topological space is denoted by LCM_{K_i} as well.

Lemma A.10 *Under the assumptions of Lemma A.4 and Lemma A.5,* BR *is a continuous map from* $LCM_{K_f} \times LCM_{K_m}$ *to itself.*

Proof: We show continuity separately along each coordinate. First, consider $M' \rightarrow \tilde{\tau}^c$. Note that as M' varies in LCM_{K_m}, by Lemma A.8, the possible fiscal best responses are in LCM_{K_f} and thus form an equicontinuous family. Hence, pointwise and uniform convergence are equivalent for the possible $\tilde{\tau}^c$'s. Now, let $M'_n \to M'$ uniformly and suppose $\tilde{\tau}^c_n \to \tilde{\tau}^c$ uniformly. Note that the latter supposition is without loss of generality since one can pass to a subsequence if necessary, which is valid because the range of BR is compact by the Arzela-Ascoli theorem. We must now show that $\tilde{\tau}^c$ is indeed the best response to M'. To this end, consider V_{h_n}, the maximal value to the fiscal authority associated with a given monetary policy rule $M'_n(z)$:

$$\begin{aligned} V_{h_n}(z) &= max_{\tau^c_n}\left\{log(c(\tau^c_n, M'_n(z))) - \alpha(c(\tau^c_n, M'_n(z)) + g) + \beta V_{h_n}\left(\frac{c(\tau^c_n, M'_n(z)) + \frac{\beta}{\alpha}zH_n(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H_n(z')}\right)\right\} \\ &= \left\{log(c(\tilde{\tau}^c_n, M'_n(z))) - \alpha(c(\tilde{\tau}^c_n, M'_n(z)) + g) + \beta V_{h_n}\left(\frac{c(\tilde{\tau}^c_n, M'_n(z)) + \frac{\beta}{\alpha}zH_n(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H_n(z')}\right)\right\} \quad (A.6) \end{aligned}$$

Here, since $M'_n \in LCM_{K_m}$, by Lemma A.2 $V_{h_n} \in CM^f$. Hence, without loss of generality, we can assume that $\{V_{h_n}\}$ has a subsequence that converges pointwise to a limit V_h, where V_h is nonincreasing, but possibly discontinuous. To complete the proof, we must show that V_h satisfies:

$$\begin{aligned} V_h(z) &= max_{\tau^c}\left\{log(c(\tau^c, M'(z))) - \alpha(c(\tau^c, M'(z)) + g) + \beta V_h\left(\frac{c(\tau^c, M'(z)) + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H(z')}\right)\right\} \\ &= \left\{log(c(\tilde{\tau}^c, M'(z))) - \alpha(c(\tilde{\tau}^c, M'(z)) + g) + \beta V_h\left(\frac{c(\tilde{\tau}^c, M'(z)) + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H(z')}\right)\right\} \quad (A.7) \end{aligned}$$

If this is the case, we can also conclude that V_h is continuous since, by Lemma A.2, if $h \in LCM_{K_m}$, then $V_h \in CM^f$. To proceed with the proof, we need to establish that, for a fixed z, the maximand in (A.6) converges uniformly in τ^c to the maximand in (A.7) and then invoke Lemma A.1. Thus, for any fixed z, define the value of the respective maximands as a function of the control τ^c:[1]

$$\begin{aligned} \tilde{V}^z_{h_n}(\tau^c) &\equiv \left\{log(c(\tau^c, M'_n(z))) - \alpha(c(\tau^c, M'_n(z)) + g) + \beta V_{h_n}\left(\frac{c(\tau^c, M'_n(z)) + \frac{\beta}{\alpha}zH_n(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H_n(z')}\right)\right\} \\ \tilde{V}^z_h(\tau^c) &\equiv \left\{log(c(\tau^c, M'(z))) - \alpha(c(\tau^c, M'(z)) + g) + \beta V_h\left(\frac{c(\tau^c, M'(z)) + \frac{\beta}{\alpha}zH(z) + g - \frac{\beta}{\alpha}}{\beta\frac{\beta}{\alpha}H(z')}\right)\right\} \end{aligned}$$

Here, for each fixed z, by virtue of the consistency condition (1.15), c is Lipschitz-continuous in (τ^c, M'), and the period payoff converges uniformly in τ^c. Similarly, as established in Lemma A.4, a conjecture by the fiscal authority such that $zH(z)$ is convex guarantees that, for every τ^c, the continuation value V_{h_n} converges to a strictly concave limit V_h. The concavity of V_h implies that it must be continuous on $int(I)$, and hence the convergence of $\{V_{h_n}\}$ to V_h is uniform in τ^c. It follows that, for a fixed $z \in int(I)$, $\tilde{V}^z_{h_n}(\tau^c)$ converges uniformly to $\tilde{V}^z_h(\tau^c)$, and under the initial hypothesis that we have $\tilde{\tau}^c_n \to \tilde{\tau}^c$ uniformly for the respective maximizers, we can apply Lemma A.1. Then, by Lemma A.1, $\tilde{\tau}^c$ is indeed the best response to M'.

[1] A minor qualification is that the feasible set for choices of τ^c in (A.6) depends on M'_n; however, this issue can be taken care of by the introduction of appropriate penalty functions which ensure that the maximum is achieved within the relevant feasible set; compare Amir (1996).

The continuity of $\tau^c \to \tilde{M}'$ is established analogously.

We are now ready for the proof of Proposition A.1.

Proof: By the Arzela-Ascoli theorem, the LCM_{K_i} are compact subsets of the Banach space of bounded continuous functions on I with the supremum norm. The same is true for the product space $LCM_{K_f} \times LCM_{K_m}$. By Lemma A.10, BR is a continuous map from $LCM_{K_f} \times LCM_{K_m}$ to itself. Finally, the LCM_{K_i} are convex subsets. Hence, all assumptions of the Schauder fixed point theorem are satisfied, and BR has a fixed point. This fixed point is a Nash equilibrium in stationary strategies.

A.4 MPE - step 1: equilibrium for arbitrary policy rule

Specifying an arbitrary policy rule φ allows to calculate the value functions for the fiscal and monetary authorities resulting from this rule when the economy starts from aggregate state z. Specifically, for the fiscal authority, conditional on the rule φ, we get $V(z;\varphi)$ as the solution to:

$$V(z;\varphi) = \{[log(c(\varphi)) - \alpha(c(\varphi)+g)] + \beta V(z';\varphi)\}$$

subject to the fiscal implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'}{(1+\mu(z';\varphi))} - c(\varphi) - \frac{\beta}{\alpha}\frac{z}{(1+\mu(\varphi))} = 0 \tag{A.8}$$

Assuming differentiability and applying an envelope condition to this problem yields:

$$V'(z;\varphi)(1+\mu(z;\varphi)) = V'(z';\varphi)(1+\mu(z';\varphi))\left[1 - \frac{z'\frac{\partial\mu(z';\varphi)}{\partial z'}}{(1+\mu(z';\varphi))}\right]^{-1}$$

Defining $\varepsilon_\mu(z;\varphi) \equiv \frac{\partial(1+\mu(z;\varphi))/\partial z}{(1+\mu(z;\varphi))/z}$, the elasticity of (gross) monetary expansions $(1+\mu(z;\varphi))$ in response to changes in the aggregate state z, we get:

$$V'(z;\varphi)(1+\mu(z;\varphi)) = V'(z';\varphi)(1+\mu(z';\varphi))\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1}, \tag{A.9}$$

where $\varepsilon_\mu(z;\varphi) \geq 0$. Moreover, the envelope condition employed above yields:

$$V'(z;\varphi) = -\lambda_f\frac{\beta}{\alpha}[(1+\mu(z;\varphi))]^{-1},$$

where the nonnegativity of λ_f, the Lagrange multiplier on the fiscal implementability constraint (A.8), together with the fact that $(1+\mu(z;\varphi)) > 0$ implies that

$V'(z;\varphi) \leq 0$.

Although the monetary authority's period payoff conincides with the fiscal authority's one, its relevant implementability constraint is different. Specifically, for the monetary authority, conditional on the rule φ, we get $W(z;\varphi)$ as the solution to:

$$W(z;\varphi) = \{[log(c(\varphi)) - \alpha(c(\varphi) + g)] + \beta W(z';\varphi)\}$$

subject to the monetary implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta z' c(z';\varphi)(1 + \tau^c(z';\varphi)) - c(\varphi) - zc(\varphi)(1 + \tau^c(\varphi)) = 0 \qquad \text{(A.10)}$$

Again assuming differentiability, applying an envelope condition to this problem and making use of the definition $\varepsilon_{c(1+\tau^c)}(z;\varphi) \equiv \frac{\partial c(z;\varphi)(1+\tau^c(z;\varphi))/\partial z}{c(z;\varphi)(1+\tau^c(z;\varphi))/z}$ for the elasticity of the private gross-of-tax consumption expenditure in response to changes in the aggregate state z, we get:

$$\frac{W'(z;\varphi)}{c(z;\varphi)(1 + \tau^c(z;\varphi))} = \frac{W'(z';\varphi)}{c(z';\varphi)(1 + \tau^c(z';\varphi))} \left[1 + \varepsilon_{c(1+\tau^c)}(z';\varphi)\right]^{-1},$$

where $\varepsilon_{c(1+\tau^c)}(z;\varphi) \leq 0$. Importantly, total differentiation of the consistency condition (1.15) reveals that $\varepsilon_{c(1+\tau^c)}(z;\varphi) = -\varepsilon_\mu(z;\varphi)$. Using this relation, we can substitute and get:

$$\frac{W'(z;\varphi)}{c(z;\varphi)(1 + \tau^c(z;\varphi))} = \frac{W'(z';\varphi)}{c(z';\varphi)(1 + \tau^c(z';\varphi))} [1 - \varepsilon_\mu(z';\varphi)]^{-1} \qquad \text{(A.11)}$$

Moreover, the envelope condition employed above yields:

$$W'(z;\varphi) = -\lambda_m c(z;\varphi)(1 + \tau^c(z;\varphi)),$$

where the nonnegativity of λ_m, the Lagrange multiplier on the implementability constraint (A.10), together with the nonnegativity of consumption an the fact that $(1 + \tau^c(z;\varphi)) > 0$ implies that $W'(z;\varphi) \leq 0$.

A.5 MPE - step 2: Optimal current policy rule for given future policy rule

A.5.1 The fiscal problem

The current fiscal authority, having inherited the aggregate state z, takes the current monetary authority's action $\pi_m = M'(z)$ as a given number and the continuation play $\varphi(z')$ as a given function of the future aggregate state z'. The problem for the fiscal authority then is:

$$\hat{V}(z;\pi,\varphi) = max_{c,z'}\{[log(c) - \alpha(c+g)] + \beta V(z';\varphi)\} \tag{A.12}$$

subject to the fiscal implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'}{(1+\mu(z';\varphi))} - c - \frac{\beta}{\alpha}\frac{z}{(1+\mu(z;\pi_m))} = 0 \tag{A.13}$$

The solution to this problem are policy functions $c_f(z;\pi,\varphi)$ and $z'_f(z;\pi,\varphi)$ for the fiscal authority. The first order condition with respect to c_f is:

$$\frac{1}{c} - \alpha = \hat{\lambda}_f = -\frac{\alpha}{\beta}\hat{V}'(z;\pi,\varphi)(1+\mu(z;\pi_m)) \tag{A.14}$$

From the envelope theorem, the optimal choice of z'_f must satisfy:

$$\hat{V}'(z;\pi,\varphi)(1+\mu(z;\pi_m)) = V'(z';\varphi)(1+\mu(z';\varphi))\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1} \tag{A.15}$$

Here, the expression on the RHS depends on the continuation policy φ; specifically we have from (A.9):

$$V'(z';\varphi)(1+\mu(z';\varphi)) = V'(z'';\varphi)(1+\mu(z'';\varphi))\left[1-\varepsilon_\mu(z'';\varphi)\right]^{-1} \tag{A.16}$$

A.5.2 The monetary problem

The current monetary authority, having inherited the aggregate state z, takes the current fiscal authority's action $\pi_f = \tau^c(z)$ as a given number and the continuation play $\varphi(z')$ as a given function of the future aggregate state z'. The problem for the monetary authority then is:

$$\hat{W}(z;\pi,\varphi) = max_{c,z'}\{[log(c) - \alpha(c+g)] + \beta W(z';\varphi)\} \tag{A.17}$$

subject to the implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta z' c(z';\varphi)(1+\tau^c(z';\varphi)) - c - zc(1+\tau^c(z;\pi_f)) = 0 \tag{A.18}$$

The solution to this problem are policy functions $c_m(z;\pi,\varphi)$ and $z'_m(z;\pi,\varphi)$ for the monetary authority. The first order condition with respect to c_m is:

$$\frac{1}{c} - \alpha = -\frac{\hat{W}'(z;\pi,\varphi)}{c(1+\tau^c(z;\pi_f))}(1+z(1+\tau^c(z;\pi_f)) \tag{A.19}$$

From the envelope theorem, the optimal choice of z'_m must satisfy:

$$\frac{\hat{W}'(z;\pi,\varphi)}{c(1+\tau^c(z;\pi_f))} = \frac{W'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))}\left[1+\varepsilon_{c(1+\tau^c)}(z';\varphi)\right]^{-1} \tag{A.20}$$

Here, the expression on the RHS depends on the continuation policy φ; specifically we have from (A.11):

$$\frac{W'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))} = \frac{W'(z'';\varphi)}{c(z'';\varphi)(1+\tau^c(z'';\varphi))}\left[1-\varepsilon_\mu(z'';\varphi)\right]^{-1} \tag{A.21}$$

A.5.3 The system of equations

The set of necessary conditions characterizing the dynamic evolution of the economy as governed by the Nash equilibrium policy response $\pi(\varphi)$ to an arbitrary continuation policy φ is given by equations (A.14), (A.15), (A.19), (A.20) and the two relevant implementability conditions (A.13), (A.18), one of which is redundant because in equilibrium they coincide due to the consistency condition (1.15). For a given future policy rule φ, the functions $V(z';\varphi)$ and $W(z';\varphi)$ as well as their derivatives and $\varepsilon_\mu(z';\varphi)$ (or equivalently $\varepsilon_{c(1+\tau^c)}(z';\varphi) = -\varepsilon_\mu(z';\varphi)$) are determined via (A.16) and (A.21). We then have a system of five equations in the five unknown variables $c(z;\pi,\varphi)$, $z'(z;\pi,\varphi)$, $\hat{\lambda}_f(z;\pi,\varphi)$, $\hat{\lambda}_m(z;\pi,\varphi)$ and $\varepsilon_\mu(z;\pi,\varphi)$. That is, the optimal current policy rule $\pi(\varphi)$, existence of which follows by standard arguments on the existence of Nash equilibrium (e.g. Theorem 2.7 in Vives, 1999), is uniquely defined with respect to the allocation (c, z') it implements in the current period and the elasticity $\varepsilon_\mu(z)$ of the monetary policy instrument.

A.6 MPE - step 3: Policy fixed point

Finally, the time consistent MPE policy rule is found as the fixed point of the functional mapping $\pi : \varphi \to \pi(\varphi)$. Existence of such a fixed point has been established in Appendix A.3.

A.7 Computational procedure

The numerical algorithm to find a MPE of the dynamic policy game proceeds as follows:

1. Guess a continuation policy rule φ.

2. For the given continuation policies φ, solve for the optimal current policy rule π; this is done by solving the system of equations collected in Appendix A.5.3. For a given future policy φ, this constitutes a system of five equations in the five unkowns c, z', λ_f, λ_m and $\varepsilon_\mu(z)$. We solve this system via a collocation method on a one-dimensional state space and obtain the current best response rule $\pi^*(\varphi)$.

3. Update the continuation policy by substituting the guess for φ by $\pi^*(\varphi)$.

4. Repeat steps 1 to 3 until $\pi^*(\varphi) = \varphi$.

Convergence of above algorithm to a specific time consistent policy rule φ is conditional on the initial guess employed in step 1. Since we suspect existence of multiple

MPE, we employ different initial guesses: The first one conjectures *some* continuation policy φ which depletes the stock of debt via the inflation tax implemented by a responsive monetary policy ($\varepsilon_\mu(z) > 0$). The second guess involves *the* continuation policy φ which keeps the stock of debt constant and balances the government budget via the consumption tax ($\varepsilon_\mu(z) = 0$). For both of these initial guesses, convergence to the conjectured MPE policy rule obtains.

Appendix B

Appendix to Chapter 2

B.1 Some notation

The aggregate state is $z^g \equiv \frac{B^g(1+R)}{M^g}$; in the rational expectations equilibrium, the representative household's state z and the aggregate state z^g coincide, so in what follows the supersript g is dropped. The current policy rule, which consists of a fiscal and a monetary rule for the present period, is $\pi(z) = (\pi_f(z), \pi_m(z))$. The future policy rule, which consists of a fiscal and a monetary rule from the next period onwards, is $\varphi(z) = (\varphi_f(z), \varphi_m(z))$. We abuse notation by letting the policy rules map the aggregate state either into the true policy instruments (τ^c, M') or alternatively - the primal approach - directly into the allocation (c, z'). Barred variables refer to predetermined private expectations.

B.2 Objective functions and implementability constraints

We employ a primal approach to solve the authorities' respective dynamic problems. Accordingly, the problem of finding optimal combinations of policy instruments is recast as a problem of finding optimal implementable allocations, where implementability requires that it must be possible to decentralize the allocation via the available distortionary policy instruments. This methodology requires a number of substitutions which make use of the private equilibrium conditions (2.7), (2.8) and (2.9). Both authorities' value functions can be constructed directly from the allocation. Due to the presence of the inflationary loss term in the monetary authority's payoff and the different dynamic constraints faced by the two authorities, we have to distinguish between two distinct value functions. It is convenient to start from the problem faced by the authorities when they assume that (i) the policy rule φ will govern the play from the next period onwards and that (ii) the current policy choice by the respective opponent is π_{-i}. The authorities take private expectations as arbitrary given functions of the aggregate state. Then, for the fiscal authority, we have:

$$\hat{V}(z;\pi,\varphi) = max_{\pi_f}\left\{[log(c) - \alpha(c+g)] + \beta V(z';\varphi)\right\}$$

For the monetary authority, one obtains:

$$\hat{W}(z;\pi,\varphi) = max_{\pi_m}\left\{-\gamma\left(\frac{\bar{c}(z)(1+\bar{\tau}^c(z))}{c(1+\tau^c(z;\pi_f))}\right)^2 + (1-\gamma)[log(c) - \alpha(c+g)] + \beta W(z';\varphi)\right\}$$

For these value functions to make sense, they must be amended by the appropriate dynamic constraints. In their respective maximization problems, both authorities are constrained by a sequence of implementability constraints which internalize the fact that the private households react optimally to the government policies. We construct these implementability constraints by substituting the private equilibrium conditions (2.7), (2.8) and (2.9) into the consoldiated government budget constraint (2.1). A complication that arises as a consequence of decision authority over policies being decentralized is that each authority's constraint depends on the policy implemented by its contemporaneous opponent. This problem is taken care of via the consistency condition (2.11) which is constructed from the private sector optimality conditions (2.8) and (2.9) together with the CIA constraints (2.7) for two adjacent periods:

$$c(1+\tau^c)\frac{M'}{M} = c(1+\tau^c)(1+\mu) = \frac{\beta}{\alpha},$$

where the first equality makes use of the definition $(1+\mu) \equiv \frac{M'}{M}$. Making use of above consistency condition, substitution of the private equilibrium conditions into the consolidated government budget constraint yields two distinct implementability constraints. For the fiscal authority, we have:

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'}{(1+\mu(z'))} - c - \frac{\beta}{\alpha}\frac{z}{(1+\mu)} = 0 \tag{B.1}$$

For the monetary authority, we have:

$$\frac{\beta}{\alpha} - g + \beta z'c(z')(1+\tau^c(z')) - c - zc(1+\tau^c) = 0 \tag{B.2}$$

Note that in both cases, the implementability constraint's job is twofold: First, for a given value of the policy instrument chosen by the other authority, it imposes a joint restriction on compatible primal choices of c and z'; secondly, since the feasible set is contingent on the policy instrument chosen by the other authority, it establishes a one-to-one mapping between the own policy instrument and the implemented allocation (c, z'). However, there is an asymmetry in the two equations: In the implementability constraint (B.1) faced by the fiscal authority, the choice variable c appears without cofactor; conversely, in the monetary authority's implementability constraint (B.2), it is scaled up by the cofactor $[1 + z(1 + \tau^c)]$. This reflects the fact that the fiscal authority's current policy choice has no direct influence on the contemporaneous price level P, whereas monetary policy, by manipulating the price level, can also affect the real value of the outstanding stock of government liabilities.

B.3 The economy as a game

The structure of the two authorities' problem to determine their policies can be described as an infinite-horizon dynamic game of almost perfect information, whose building block is a two-player simultaneous-moves stage game $\mathcal{G}(z;\varphi) = \Big(f, m; A_f(z), A_m(z); \hat{V}(z;\pi,\varphi), \hat{W}(z;\pi,\varphi)\Big)$. We are now going to define the components of the stage game. To begin with, the game is not of a repeated variety due to the presence of the endogenous state variable $z \equiv \frac{B(1+R)}{M}$. The players are the fiscal and the monetary authority, indicated by $i = f, m$ respectively. In each period, their actions are $a_f = \tau^c$ and $a_m = M'$. The strategy/action spaces for the two players are compact and time-invariant and are given by $A_f(z) = [\tau^c_{min}(z), \tau^c_{max}(z)]$ and $A_m(z) = [M'_{min}(z), M'_{max}(z)]$, where, for all z, $\tau^c_{min}(z) > -1$, $M'_{min}(z) > 0$ and $\tau^c_{max}(z), M'_{max}(z) < \bar{X}$ for some finite $\bar{X}$. Note that, if the aggregate state variable z is assumed to live in a compact interval $I = [\underline{Z}, \bar{Z}]$, then consistency dictates that the admissible action spaces depend on z. However, the interval I can be assumed to be sufficiently large such as not to constrain the players' equilibrium choices. Finally, the restriction of the players' strategy spaces to comprise only mappings from the aggregate state z into actions qualifies the model as a discounted Markov-stationary game with uncountable state and action spaces.

B.4 MPE - step 1: equilibrium for arbitrary policy rule

Specifying an arbitrary policy rule φ allows to calculate the value functions for the fiscal and monetary authorities resulting from this rule when the economy starts from aggregate state z. Specifically, for the fiscal authority, conditional on the rule φ, we get $V(z;\varphi)$ as the solution to:

$$V(z;\varphi) = \{[log(c(\varphi)) - \alpha(c(\varphi) + g)] + \delta V(z';\varphi)\}$$

subject to the fiscal implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'}{(1+\mu(z';\varphi))} - c(\varphi) - \frac{\beta}{\alpha}\frac{z}{(1+\mu(\varphi))} = 0 \tag{B.3}$$

Assuming differentiability and applying an envelope condition to this problem yields:

$$V'(z;\varphi)(1+\mu(z;\varphi)) = \frac{\delta}{\beta}V'(z';\varphi)(1+\mu(z';\varphi))\left[1 - \frac{z'\frac{\partial\mu(z';\varphi)}{\partial z'}}{(1+\mu(z';\varphi))}\right]^{-1}$$

Defining $\varepsilon_\mu(z;\varphi) \equiv \frac{\partial(1+\mu(z;\varphi))/\partial z}{(1+\mu(z;\varphi))/z}$, the elasticity of (gross) monetary expansions $(1+\mu(z;\varphi))$ in response to changes in the aggregate state z, we get:

$$V'(z;\varphi)(1+\mu(z;\varphi)) = \frac{\delta}{\beta}V'(z';\varphi)(1+\mu(z';\varphi))\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1}, \tag{B.4}$$

where $\varepsilon_\mu(z;\varphi) \geq 0$. Moreover, the envelope condition employed above reads:

$$V'(z;\varphi) = -\lambda_f\frac{\beta}{\alpha}[(1+\mu(z;\varphi))]^{-1},$$

where the nonnegativity of λ_f, the Lagrange multiplier on the fiscal implementability constraint (B.3), together with the fact that $(1+\mu(z;\varphi)) > 0$ implies that $V'(z;\varphi) \leq 0$.

Similarly, for the monetary authority, conditional on the rule φ, we get $W(z;\varphi)$ as the solution to:

$$W(z;\varphi) = \left\{-\gamma\left(\frac{\bar{c}(z)(1+\bar{\tau}^c(z))}{c(\varphi)(1+\tau^c(\varphi))}\right)^2 + (1-\gamma)[log(c(\varphi)) - \alpha(c(\varphi)+g)] + \beta W(z';\varphi)\right\}$$

subject to the monetary implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta z'c(z';\varphi)(1+\tau^c(z';\varphi)) - c(\varphi) - zc(\varphi)(1+\tau^c(\varphi)) = 0 \tag{B.5}$$

Again assuming differentiability, applying an envelope condition to this problem and making use of the definition $\varepsilon_{c(1+\tau^c)}(z;\varphi) \equiv \frac{\partial c(z;\varphi)(1+\tau^c(z;\varphi))/\partial z}{c(z;\varphi)(1+\tau^c(z;\varphi))/z}$ for the elasticity of the private gross-of-tax consumption expenditure in response to changes in the aggregate state z, we get:

$$\frac{W'(z;\varphi)}{c(z;\varphi)(1+\tau^c(z;\varphi))} + \frac{2\gamma\frac{\varepsilon_{c(1+\tau^c)}(z;\varphi)}{z}}{c(z;\varphi)(1+\tau^c(z;\varphi))} = \frac{W'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))}\left[1+\varepsilon_{c(1+\tau^c)}(z';\varphi)\right]^{-1},$$

where $\varepsilon_{c(1+\tau^c)}(z;\varphi) \leq 0$. Importantly, total differentiation of the consistency condition (2.11) reveals that $\varepsilon_{c(1+\tau^c)}(z;\varphi) = -\varepsilon_\mu(z;\varphi)$. Using this relation, we can substitute and get:

$$\frac{W'(z;\varphi)}{c(z;\varphi)(1+\tau^c(z;\varphi))} - \frac{2\gamma\frac{\varepsilon_\mu(z;\varphi)}{z}}{c(z;\varphi)(1+\tau^c(z;\varphi))} = \frac{W'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))}\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1} \tag{B.6}$$

Moreover, the envelope condition employed above reads:

$$W'(z;\varphi) = 2\gamma\frac{\varepsilon_\mu(z;\varphi)}{z} - \lambda_m c(z;\varphi)(1+\tau^c(z;\varphi)),$$

where we observe that $W'(z;\varphi) \leq 0$. Formally, this follows from the first order condition with respect to z':

$$W'(z';\varphi) = -\lambda_m c(z';\varphi)(1+\tau^c(z';\varphi))\left[1-\varepsilon_\mu(z';\varphi)\right],$$

where the nonnegativity of λ_m, the Lagrange multiplier on the monetary implementability constraint (B.5), together with the nonnegativity of consumption an the fact that $(1+\tau^c(z;\varphi)) > 0$ implies that $W'(z;\varphi) \leq 0$.

B.5 MPE - step 2: Optimal current policy rule for given future policy rule

B.5.1 The fiscal problem

The current fiscal authority, having inherited the aggregate state z, takes the current monetary authority's policy $\pi_m = M'(z)$ as a given number and the continuation play $\varphi(z')$ as a given function of the future aggregate state z'. The problem for the fiscal authority then is:

$$\hat{V}(z;\pi,\varphi) = max_{c,z'}\{[log(c) - \alpha(c+g)] + \delta V(z';\varphi)\} \tag{B.7}$$

subject to the fiscal implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta\frac{\beta}{\alpha}\frac{z'}{(1+\mu(z';\varphi))} - c - \frac{\beta}{\alpha}\frac{z}{(1+\mu(z;\pi_m))} = 0 \tag{B.8}$$

The solution to this problem are policy functions $c_f(z;\pi,\varphi)$ and $z'_f(z;\pi,\varphi)$ for the fiscal authority. The first order condition with respect to c_f is:

$$\frac{1}{c} - \alpha = -\frac{\alpha}{\beta}\hat{V}'(z;\pi,\varphi)(1+\mu(z;\pi_m)) \tag{B.9}$$

From the envelope theorem, the optimal choice of z'_f must satisfy:

$$\hat{V}'(z;\pi,\varphi)(1+\mu(z;\pi_m)) = \frac{\delta}{\beta}V'(z';\varphi)(1+\mu(z';\varphi))\left[1-\varepsilon_\mu(z';\varphi)\right]^{-1} \tag{B.10}$$

Here, the expression on the RHS depends on the continuation policy φ; specifically, we have from (B.4):

$$V'(z';\varphi)(1+\mu(z';\varphi)) = \frac{\delta}{\beta}V'(z'';\varphi)(1+\mu(z'';\varphi))\left[1-\varepsilon_\mu(z'';\varphi)\right]^{-1} \tag{B.11}$$

B.5.2 The monetary problem

The current monetary authority, having inherited the aggregate state z as well as predetermined private expectations $\bar{c}(z)$, $\bar{\tau}^c(z)$, takes the current fiscal authority's policy $\pi_f = \tau^c(z)$ as a given number and the continuation play $\varphi(z')$ as a given function of the future aggregate state z'. The problem for the monetary authority then is:

$$\hat{W}(z;\pi,\varphi) = max_{c,z'} \left\{ -\gamma \left(\frac{\bar{c}(z)(1+\bar{\tau}^c(z))}{c(1+\tau^c(z;\pi_f))} \right)^2 + (1-\gamma)[log(c) - \alpha(c+g)] + \beta W(z';\varphi) \right\} \tag{B.12}$$

subject to the implementability constraint:

$$\frac{\beta}{\alpha} - g + \beta z' c(z';\varphi)(1+\tau^c(z';\varphi)) - c - zc(1+\tau^c(z;\pi_f)) = 0 \tag{B.13}$$

The solution to this problem are policy functions $c_m(z;\pi,\varphi)$ and $z'_m(z;\pi,\varphi)$ for the monetary authority. The first order condition with respect to c_m is:

$$2\gamma\frac{1}{c} + (1-\gamma)\left(\frac{1}{c} - \alpha\right) = -\frac{\hat{W}'(z;\pi,\varphi) + 2\gamma\frac{\varepsilon_{c(1+\tau^c)}(z;\pi_f)}{z}}{c(1+\tau^c(z;\pi_f))}[1 + z(1+\tau^c(z;\pi_f)] \tag{B.14}$$

From the envelope theorem, the optimal choice of z'_m must satisfy:

$$\frac{\hat{W}'(z;\pi,\varphi) + 2\gamma\frac{\varepsilon_{c(1+\tau^c)}(z;\pi_f)}{z}}{c(1+\tau^c(z;\pi_f))} = \frac{W'(z';\varphi)}{c(z';\varphi)(1+\tau^c(z';\varphi))}\left[1 + \varepsilon_{c(1+\tau^c)}(z';\varphi)\right]^{-1} \tag{B.15}$$

Here, the expression on the RHS depends on the continuation policy φ; specifically, we have from (B.6):

$$\frac{W'(z';\varphi) - 2\gamma\frac{\varepsilon_\mu(z';\varphi)}{z'}}{c(z';\varphi)(1+\tau^c(z';\varphi))} = \frac{W'(z'';\varphi)}{c(z'';\varphi)(1+\tau^c(z'';\varphi))}[1 - \varepsilon_\mu(z'';\varphi)]^{-1} \tag{B.16}$$

B.5.3 The system of equations

The set of necessary conditions characterizing the dynamic evolution of the economy as governed by the Nash equilibrium policy response $\pi(\varphi)$ to an arbitrary continuation policy φ is given by equations (B.9), (B.10), (B.14), (B.15) and the two relevant implementability conditions (B.8), (B.13), one of which is redundant because in equilibrium they coincide due to the consistency condition (2.11). For a given future policy rule φ, the functions $V(z';\varphi)$ and $W(z';\varphi)$ as well as their derivatives and $\varepsilon_\mu(z';\varphi)$ (or equivalently $\varepsilon_{c(1+\tau^c)}(z';\varphi)$) are determined via (B.11) and (B.16). We then have a system of five equations in the five unknown variables $c(z;\pi,\varphi)$, $z'(z;\pi,\varphi)$, $\hat{\lambda}_f(z;\pi,\varphi)$, $\hat{\lambda}_m(z;\pi,\varphi)$ and $\varepsilon_\mu(z;\pi,\varphi)$. That is, the optimal current policy rule $\pi(\varphi)$ is uniquely defined with respect to the allocation (c, z') it implements in the current period and the elasticity $\varepsilon_\mu(z)$ of the monetary policy instrument.

B.6 MPE - step 3: Policy fixed point

Finally, the time consistent MPE policy rule is found as the fixed point of the functional mapping $\pi : \varphi \to \pi(\varphi)$. Existence of such a fixed point follows from results obtained in chapter one.

B.7 Computational procedure

Traditionally, dynamic games have been attacked by linear-quadratic methods which allow for relative simple algorithms to find a solution. However, in many economic applications, linear-quadratic applications deliver highly inaccurate approximate solutions; see e.g. the discussion in Miranda and Fackler (2002). Particularly, since linear-quadratic methods are local in nature, this is the case at points far away from the certainty-equivalent steady state or if the true payoff and transition functions are not well-approximated by second- and first-degree polynomials over the entire domain. Therefore, standard linear-quadratic methods do not seem appropriate to solve our model; the main complication stems from the presence of the endogenous state variable z whose steady state value z^* is a priori unknown. Projection methods have recently been proposed as an efficient way to solve functional equation problems, and, more specifically, dynamic games. To the best of our knowledge, the application to a primal approach problem in a general equilibrium context is new. The numerical algorithm to find the MPE of the dynamic policy game proceeds as follows:

1. Guess an arbitrary continuation policy rule φ.
2. For the given continuation policy φ, solve for the optimal current policy rule π; this is done by solving the system of equations collected in Appendix B.5.3. For a given future policy φ, this constitutes a system of five equations in the five unkowns c, z', λ_f, λ_m and ε_μ. We solve this system via a collocation method on a one-dimensional state space and obtain the current best response rule $\pi^*(\varphi)$.
3. Update the continuation policy by substituting the guess for φ by $\pi^*(\varphi)$.
4. Repeat steps 1 to 3 until $\pi^*(\varphi) = \varphi$.

Appendix C

Appendix to Chapter 3

C.1 Competitive equilibrium and financial contracting

Below, we present the optimality conditions characterizing the solution to the model economy's agents' decision problems, lay out the details of the financial contracting scheme between entrepreneurs and the financial intermediary and then define a competitive equilibrium.

C.1.1 Optimal decisions: Households

The solution to the household problem (3.4) can be summarized by a set of optimality conditions which determine the household's equilibrium behavior. First, there is the Euler equation describing the optimal intertemporal allocation of nominal wealth:

$$E_{t^-}\left\{\frac{u_c(c_t^H,h_t^H)}{P_t}-\beta\tilde{R}_t\frac{u_c(c_{t+1}^H,h_{t+1}^H)}{P_{t+1}}\right\}=0 \tag{C.1}$$

Next, there are two Euler equations which determine the sequence of dynamic decisions between consumption and technology-specific capital investments; for $i=k,z$, they read:

$$u_c(c_t^H,h_t^H)\left[1+\Phi_2(i_t,i_{t+1})\right]=\beta E_t\left\{u_c(c_{t+1}^H,h_{t+1}^H)\left[(1-\delta)-\Phi_1(i_{t+1},i_{t+2})\right]+\beta\frac{u_c(c_{t+2}^H,h_{t+2}^H)}{P_{t+2}}R_{t+1}^i\right\} \tag{C.2}$$

An immediate implication of the two equations (C.2) is that the technology-specific returns to capital must be equal in expectation, i.e. $E_t\{R_{t+1}^k\}=E_t\{R_{t+1}^z\}=E_t\{R_{t+1}\}$. Similarly, there are two optimality conditions which govern the household's consumption-leisure choice, thus pinning down the optimal supply of labor to either production plan $i=k,z$:

$$u_h(c_t^H,h_t^H)+\left[\theta\frac{u_c(c_t^H,h_t^H)}{P_t}+(1-\theta)\beta E_t\left\{\frac{u_c(c_{t+1}^H,h_{t+1}^H)}{P_{t+1}}\right\}\right]W_t^{i,H}=0 \tag{C.3}$$

Here, it follows that, in all states of the world, the technology-specific wage rates must be identical because the household cares only about aggregate labor supply; hence, we have $W_t^{k,H} = W_t^{z,H} = W_t^H$.

C.1.2 Optimal decisions: Entrepreneurs

Basic technology: The entrepreneur's problem (3.5) when employing the basic technology reduces to a standard classical production plan: By constant returns to scale, efficient factor employment implies that marginal costs are independent of the quantity produced, i.e. $C(W_t^k, R_t^k, \tilde{R}_t; y_t^k) = MC_t^k(W_t^k, R_t^k, \tilde{R}_t; 1)y_t^k$. Then, from the assumption of perfectly competitive intermediate goods markets, it follows that the price of the basic intermediate good equals marginal costs, i.e. $P_t^k = MC_t^k(W_t^k, R_t^k, \tilde{R}_t)$. From the Cobb-Douglas specification of $\varphi(k_t, l_t^k)$, optimal factor demands for the basic production plan are:

$$k_t = \frac{\alpha^k P_t^k y_t^k}{R_t^k} \qquad \text{and} \qquad l_t^k = \frac{(1-\alpha^k)P_t^k y_t^k}{[1+\theta(\tilde{R}_t - 1)]W_t^k} \tag{C.4}$$

Finally, the price for the basic intermediate good is:

$$P_t^k = \frac{1}{\mathcal{A}_t}\left(\frac{R_t^k}{\alpha^k}\right)^{\alpha^k}\left(\frac{[1+\theta(\tilde{R}_t - 1)]W_t^k}{(1-\alpha^k)}\right)^{(1-\alpha^k)} \tag{C.5}$$

Advanced technology: Production by means of the advanced technology is subject to an entrepreneurial ex post moral hazard problem. This agency problem is dealt with via a financial contract whose specification closely follows Homström and Tirole (1998) and is described next.

C.1.3 Financial contracting

Optimal factor input ratio and the cost function: Part of an optimal contract must be to use factor inputs in a cost minimizing combination. Since factor demands are determined via the constrained-efficient contract $\mathcal{C}_t$ solving program (3.7), they will not only reflect the entrepreneur's profit maximization objective, but also the intermediary's need to break even in expectation. From the Cobb-Douglas specification, the possibility of project failure then requires that factors earn constant shares not of project revenue, but of the total costs $C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)$ associated with a targeted production scale $\tilde{y}_t^z$. Hence, the demands for capital and labor to be employed in a generic advanced project are:

$$z_t = \frac{\alpha^z C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)}{R_t^z} \qquad \text{and} \qquad l_t^z = \frac{(1-\alpha^z) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)}{[1+\theta(\tilde{R}_t - 1)]W_t^z} \tag{C.6}$$

Furthermore, from constant returns to scale and the Cobb-Douglas specification of the technology, we can write:

$$C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) = MC_t^z\left(W_t, R_t^z, \tilde{R}_t\right)\tilde{y}_t^z = \frac{1}{\mathcal{V}_t}\left(\frac{R_t}{\alpha^z}\right)^{\alpha^z}\left(\frac{[1+\theta(\tilde{R}_t-1)]W_t^z}{(1-\alpha^z)}\right)^{(1-\alpha^z)}\tilde{y}_t^z,$$

where $MC_t^z(\cdot)$ are the per unit costs of producing a targeted output level $\tilde{y}_t^z$; since the technology displays constant returns to scale, these per unit costs coincide with marginal costs. As a consequence, the program to find the optimal contract is linear in the project size $\tilde{y}_t^z$.

First best - the socially optimal contract: Consider the first best contract where $b = 0$ such that the entrepreneurial moral hazard problem plays no role, but liquidity is scarce and has an opportunity cost $\tilde{R}_t$. The questions asked here are: What is the maximum overall return on investment? And how does the corresponding socially optimal contract look like? Suppose for the moment a binding participation constraint for the investor; indeed, we will later verify that this is the case in a well-specified problem.[1] Substituting from the binding participation constraint (3.7b) into the entrepreneur's net return (3.7a) yields:

$$\Pi_t^F = \left[\int \Gamma_t(\xi_t)\frac{P_t^z}{MC_t^z(\cdot)}\left(1-\xi_t\tilde{R}_t\right)dG(\xi_t) - 1\right]MC_t^z(\cdot)\tilde{y}_t^z$$

Let $\hat{\xi}_t$ denote the cutoff value for the liquidity shock such that the project is continued if and only if $\xi_t \leq \hat{\xi}_t$; using this rule for the indicator function $\Gamma_t(\xi_t)$ then allows to rewrite the entrepreneur's net return as:

$$\Pi_t^F(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t)MC_t^z(\cdot)\tilde{y}_t^z, \tag{C.7a}$$

where:

$$\lambda_t(\hat{\xi}_t) \equiv \left[\int_0^{\hat{\xi}_t}\frac{P_t^z}{MC_t^z(\cdot)}\left(1-\xi_t\tilde{R}_t\right)dG(\xi_t) - 1\right] \tag{C.7b}$$

In definition (C.7b), $\lambda_t(\hat{\xi}_t)$ denotes the *net social marginal return* on one unit invested in the individual advanced project, given a cutoff value $\hat{\xi}_t$. Since $\frac{P_t^z}{MC_t^z(\cdot)} > 0$, $\lambda(\hat{\xi}_t)$ is maximized at the socially optimal cutoff value $\hat{\xi}_t^{FB} = \frac{1}{\tilde{R}_t}$. Moreover, from (C.7a), it is clear that the entrepreneur is the residual claimant and receives the full social surplus from the project.

[1] By well-specified, we mean (i) that there is no self-financing, and (ii) that the solution to the constrained-optimal contract features a finite investment level.

Second best - entrepreneurial moral hazard: Now consider the case where $b > 0$. Notice that general equilibrium considerations imply that the marginal net social return under both the first and the second best solution must be positive.[2] Then, given a positive value for $\lambda_t(\hat{\xi}_t)$, the entrepreneur will seek to maximize $\Pi_t^F(\hat{\xi}_t)$ by choosing the maximum investment volume $MC_t^z(\cdot)\tilde{y}_t^z$ that still guarantees investor participation. But from (3.7b), this is achieved by maximizing the state contingent per unit transfer $\tau_t(\xi_t)$ to the investor. Accordingly, the second best contract prescribes to retain the minimum amount of profits that is still consistent with incentive compatibility. Hence, the entrepreneur's incentive compatibility constraint (3.7c) is binding at the maximum pledgeable unit return:

$$\tau_t(\xi_t) = \frac{\Gamma_t(\xi_t)(1-b)P_t^z\tilde{y}_t^z}{MC_t^z(\cdot)\tilde{y}_t^z} \tag{C.8}$$

We can now solve for the largest investment volume $MC_t^z(\cdot)\tilde{y}_t^z$ that is compatible with both the investor's participation constraint and the entrepreneur's incentive constraint by substituting (C.8) into the investor's participation constraint (3.7b) to obtain:

$$\left[1 - \int \Gamma(\xi_t)\left((1-b) - \xi_t\tilde{R}_t\right)\frac{P_t^z}{MC_t^z(\cdot)}dG(\xi_t)\right]MC_t^z(\cdot)\tilde{y}_t^z = E_t \tag{C.9}$$

Here, the expression in squared brackets represents the difference between marginal cost of investment to an outside investor and the expected marginal return to such outside investment. Let $\hat{\xi}_t^0 \equiv \frac{(1-b)}{\tilde{R}_t}$ denote the cutoff value that maximizes the expected marginal return to outside investors, and note that (C.9) implies that, given some $E_t > 0$, the expected (subject to idiosyncratic liquidity shocks) marginal return on outside investment is strictly smaller than one.[3]

Solving (C.9) for the maximum investment volume conditional on a given cutoff value $\hat{\xi}_t$, allows to write the project's investment capacity as:

$$MC_t^z(\cdot)\tilde{y}_t^z \;=\; \mu_t(\hat{\xi}_t)E_t, \tag{C.10a}$$

[2]To see this, suppose to the contrary that $\lambda(\hat{\xi}_t^{FB}) \leq 0$ such that the optimal contract would prescribe $z_t = l_t^z = 0$, i.e. zero investment for any level of entrepreneurial equity E_t. However, this implies $\tilde{y}_t^z = 0$ which contradicts a general equilibrium with positive consumption and investment, and the price of the advanced intermediate good would adjust such as to guarantee a positive marginal net social return. By the same token, the second best solution must also involve a cutoff rule $\hat{\xi}_t$ with positive marginal net social return.

[3]Indeed, if this was not the case, investment would be self-financing and there would be no demand for liquidity at all in that the investor's participation constraint would be non-binding. A sufficient condition for ruling out self-financing is: $\int_0^{\hat{\xi}_t^0}\left((1-b) - \xi_t\tilde{R}_t\right)\frac{P_t^z}{MC_t^z(\cdot)}dG(\xi_t) < 1$. Observe that rewriting this condition yields $\lambda_t(\hat{\xi}_t^0) < b\frac{P_t^z}{MC_t^z(\cdot)}G(\hat{\xi}_t^0)$; then, it is apparent that $\hat{\xi}_t^{FB} = \hat{\xi}_t^0$ if $b = 0$, which leads to the conclusion that, in order to rule out self-financing, a positive wedge $\hat{\xi}_t^{FB} - \hat{\xi}_t^0 > 0$ and therefore $b > 0$ are essential.

where:

$$\mu_t(\hat{\xi}_t) \quad \equiv \quad \frac{1}{1 - \int_0^{\hat{\xi}_t} \left((1-b) - \xi_t \tilde{R}_t\right) \frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t)} \tag{C.10b}$$

is an *equity multiplier*, whose denominator specifies the amount of internal funds that the entrepreneur has to contribute per unit of investment in order to compensate the outside investor for the shortfall implied by the expression in squared brackets in (C.9). Finally, using (C.7a) and (C.10a), the entrepreneur's expected net payoff becomes:

$$\Pi_t^F(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t)\mu_t(\hat{\xi}_t)E_t \tag{C.11}$$

It now remains to determine the second best continuation threshold, to be denoted $\hat{\xi}_t^*$. Given an entrepreneurial equity position E_t, the second best cutoff $\hat{\xi}_t^*$ maximizes (C.11). It is clear that $\hat{\xi}_t^* \in [\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$: If $\xi_t < \hat{\xi}_t^0$, both parties prefer to continue ex post because both parties can realize gains on the sunk stage one investment; if $\xi_t > \hat{\xi}_t^{FB}$, both parties prefer to abandon the project because the net social marginal return of continuing is negative. Within the interval $[\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$, there emerges a trade-off: On the one hand, increasing $\hat{\xi}_t$ implies that continuation is possible in more contingencies, and thus the marginal net social return $\lambda_t(\hat{\xi}_t)$ on each unit of initial investment is increased. On the other hand, decreasing $\hat{\xi}_t$ allows to increase the amount of initial investment $MC_t^z(\cdot)\tilde{y}_t^z$ by increasing the equity multiplier $\mu_t(\hat{\xi}_t)$. After substitution from the definitions (C.7b) and (C.10b) into (C.11), it is straightforward to show that the optimal continuation value $\hat{\xi}_t^*$ can be found as the solution to the following problem:

$$\min_{\hat{\xi}_t} \frac{\tilde{R}_t \int_0^{\hat{\xi}_t} \xi_t dG(\xi_t) + \frac{MC_t^z(\cdot)}{P_t^z}}{G(\hat{\xi}_t)}, \tag{C.12}$$

which has the interpretation that the second best cutoff value minimizes the expected unit cost of total expected investment. The first order condition to this problem is:

$$\int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t = \frac{MC_t^z(\cdot)}{P_t^z} \frac{1}{\tilde{R}_t} \tag{C.13}$$

Finally, using the optimality condition for the cutoff value allows to rewrite the entrepreneur's expected net return in the following compact form:

$$\Pi_t^F(\hat{\xi}_t^*) = \frac{\frac{1}{\tilde{R}_t} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \frac{(1-b)}{\tilde{R}_t}} E_t = \frac{\hat{\xi}_t^{FB} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \hat{\xi}_t^0} E_t \tag{C.14}$$

Observe how this expression reflects the trade-off underlying the choice of $\hat{\xi}_t^* \in [\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$. For reference, we define the *expected net return per unit of entrepreneurial* *equity* E_t as:

$$\tilde{\Pi}_t^F(\hat{\xi}_t^*) \equiv \frac{\frac{1}{\tilde{R}_t} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \frac{(1-b)}{\tilde{R}_t}}$$

Since the optimal contract is linear in the individual entrepreneur's equity position, any individual entrepreneur's conditions are also relevant in the aggregate. As a result, the first order condition (C.13) pins down the price level for the intermediate goods produced by means of the advanced technology:

$$P_t^z = \frac{1}{\tilde{R}_t \int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t} \frac{1}{\mathcal{V}_t} \left(\frac{R_t^z}{\alpha^z}\right)^{\alpha^z} \left(\frac{[1+\theta(\tilde{R}_t - 1)]W_t^z}{(1-\alpha^z)}\right)^{(1-\alpha^z)} \tag{C.15}$$

C.1.4 Implementation and discussion of second best policy

Aggregating across advanced projects, we can derive two measures of aggregate liquidity demand. The first one is relevant if liquidity provision is organized in a way that disregards the scope for risk sharing across entrepreneurs:

$$\bar{D}_t = \hat{\xi}_t^* P_t^z \tilde{y}_t^z \tag{C.16a}$$

In contrast, the second measure of overall liquidity demand is relevant if liquidity risk can be pooled across projects:

$$D_t^* = \left[\int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t\right] P_t^z \tilde{y}_t^z < \bar{D}_t \tag{C.16b}$$

It is clear that this latter concept requires some form of financial intermediation. Hence, drawing on Holmström and Tirole (1998), we turn to the institutional details supporting the implementation of the second best policy.

One possibility is to have the financial intermediary initially extend the amount $MC_t^z(\cdot)\tilde{y}_t^z - E_t$ to the entrepreneur together with an *irrevocable line of credit* of maximum size $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$ to be drawn from as needed at the interim stage. Given our assumptions on the details of the moral hazard problem which does not envisage distraction of resources on the part of the entrepreneur, this credit line implements the second best solution as long as it is provided free of charge, irrespective of the amount $\xi_t P_t^z \tilde{y}_t^z \leq \hat{\xi}_t^* P_t^z \tilde{y}_t^z$ of liquidity actually requested. Since the liquidity shocks are independent across projects, the aggregate amount of resources needed to cover refinancing needs at the interim stage is then given by D_t^*. At the level of an individual entrepreneur, an alternative would be via a *liquidity covenant* which involves the financial intermediary initially extending the amount $[1 + (P_t^z / MC_t^z(\cdot))\hat{\xi}_t^*] MC_t^z(\cdot)\tilde{y}_t^z - E_t$ to the entrepreneur, whereby the requirement is imposed that the amount $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$ is not sunk in the project, but kept in the form of readily marketable assets. However, at the aggregate level across all projects, implementation of the second best policy via liquidity covenants is seen to require strictly more resources $\bar{D}_t > D_t^*$ because liquidity is kept separately for each project, thus forgoing the potential to pool liquidity across them.[4]

Given our empirical interest, the question arises whether there is a second best policy which features the productive sector (rather than the intermediary) holding liquidity. We now give an example for such a policy. For that purpose, first define a number $\check{\xi}_t$ which is implicitly given by $D_t^* = \check{\xi}_t P_t^z \tilde{y}_t^z$; then, a policy of the desired kind is constructed as follows: At stage one, the intermediary extends the amount $[1 + (P_t^z / MC_t^z(\cdot))\check{\xi}_t] MC_t^z(\cdot)\tilde{y}_t^z - E_t$ to the entrepreneur. The financial contract further stipulates that the amount $\check{\xi}_t P_t^z \tilde{y}_t^z$ must be held in the form of liquid assets. The entrepreneur will then use the obtained external finance to complement her own equity position E_t sunk in the project by the maximum admissible amount $MC_t^z(\cdot)\tilde{y}_t^z - E_t$ and deposit her remaining liquid assets with the intermediary (at zero interest). Now, at stage two, when hit by a liquidity shock ξ_t, the entrepreneur must first use up her own asset position of $\check{\xi}_t P_t^z \tilde{y}_t^z$; only then can she approach the intermediary for additional funds, which the latter will residually provide up to the second best quantity $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$. The intermediary is able to provide this liquidity by calling idle funds from those projects who receive shocks $\xi_t < \check{\xi}_t$. Obviously, this policy replicates the second best in terms of both the initial investment scale and the cutoff $\hat{\xi}_t^*$. Thus, it only remains to check whether above arrangement is feasible, which is the case since, from the definition of $\check{\xi}_t$, the supply of and demand for liquidity are equal at the aggregate level: $P_t^z \tilde{y}_t^z \check{\xi}_t = D_t^* = P_t^z \tilde{y}_t^z \int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t$. Further variations on the institutional structure implementing the second best, involving advanced sector projects holding assets other than cash (e.g. corporate debt issued by the basic sector firms) as well as liquid assets earning non-zero rates of retun, are possible.

C.1.5 Competitive equilibrium

Definition C.1 (Competitive Equilibrium) *Given initial conditions*

[4] In the benchmark section of their paper which features an exogenous supply of liquidity, Holmström and Tirole (1998) establish equivalence of the two discussed methods of providing liquidity. This result stems from the fact that their economy allows for a technology ("cash") to transfer wealth across the stages of the financial contracting problem and the additional assumption that "cash" is not scarce. Conversely, in our economy "cash" is available, but its (limited) supply is determined in general equilibrium via households' financial deposits and monetary policy. Importantly then, liquidity is costly (it sells at a premium $\tilde{R}_t - 1 > 0$), and agents have an incentive to economize on its usage. The consequence is that intermediated credit lines and decentralized corporate liquidity holdings are no longer equivalent.

$\{k_0, z_0, A_0, M_0\}$ *and realizations for aggregate shocks* $\{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}_{t=0}^{\infty}$ *and idiosyncratic shocks* $\{\xi_t^i\}_{t=0}^{\infty}$*, a competitive equilibrium is a list of allocations* $\{c_t^H, h_t^{k,H}, h_t^{z,H}, x_t, k_{t+1}, z_{t+1}, Q_t, M_{t+1}\}_{t=0}^{\infty}$ *to households and* $\{(c_t^E, h_t^{k,E}, h_t^{z,E}, E_t, A_{t+1})^i\}_{t=0}^{\infty} \forall i$ *to entrepreneurs, of technology-specific and economywide aggregates* $\{c_t, l_t^k, l_t^z, L_t, K_{t+1}, y_t^k, y_t^z, y_t\}_{t=0}^{\infty}$ *and of prices* $\{P_t, P_t^z, P_t^k, W_t, W_t^k, W_t^{k,H}, W_t^{k,E}, W_t^z, W_t^{z,H},$ $W_t^{z,E}, R_t, R_t^k, R_t^z, \tilde{R}_t\}_{t=0}^{\infty}$ *such that:*

1. *given prices, the allocation solves the household problem (3.4) as well as the basic and advanced production problems (3.5) and (3.7);*

2. *entrepreneurs follow their behavioral rules and the financial intermediary breaks even;*

3. *aggregation across agents and sectors as well as among the entrepreneurs obtains, i.e. for a generic variable* $(v_t^E)^i$ *belonging to the allocation to entrepreneurs:* $\int_i v_t^{E,i} di = v_t^E$*;*

4. *the financial market as well as the markets for final goods, intermediate goods and factor inputs clear.*

C.2 TFP accounting

Our model assumes that entrepreneurial firms can employ two different Cobb-Douglas technologies which are homogenous in their two respective input factors, capital and labor: $\varphi(k_t, l_t^k) = (k_t)^{\alpha^k}((1+\gamma)^t l_t^k)^{(1-\alpha^k)}$ and $f(z_t, l_t^z) = (z_t)^{\alpha^z}((1+\gamma)^t l_t^z)^{(1-\alpha^z)}$. Thus, the equations determining the distinct intermediate outputs read $y_t^k = \mathcal{A}_t \varphi(k_t, l_t^k)$ and $y_t^z = G(\hat{\xi}_t^*)\tilde{y}_t^z = \mathcal{V}_t G(\hat{\xi}_t^*) f(z_t, l_t^z)$. Totally differentiating both equations and dropping time subscripts yields:

$$
\begin{aligned}
dy^k &= d\mathcal{A}\varphi(k, l^k) + \mathcal{A}\left(\varphi_k(k, l^k)dk + \varphi_l(k, l^k)dl^k\right) \\
dy^z &= \left(d\mathcal{V}G(\cdot) + \mathcal{V}g(\cdot)d\hat{\xi}^*\right) f(z, l^z) + \mathcal{V}G(\cdot)\left(f_z(z, l^z)dz + f_l(z, l^z)dl^z\right)
\end{aligned}
$$

Dividing these equations by $\mathcal{A}\varphi(k, l^k)$ and $\mathcal{V}G(\cdot)f(z, l^z)$, respectively, one obtains the approximate percentage deviations (denoted by hats) of the two intermediate outputs:

$$
\begin{aligned}
\widehat{y^k} &= \widehat{\mathcal{A}} + \alpha^k \widehat{k} + (1-\alpha^k)\widehat{l^k} \\
\widehat{y^z} &= \widehat{\mathcal{V}} + \omega_{\hat{\xi}^*}^G \widehat{\hat{\xi}^*} + \alpha^z \widehat{z} + (1-\alpha^z)\widehat{l^z},
\end{aligned}
$$

where $\widehat{x} \equiv \frac{dx}{x}$ and where $\omega_{\hat{\xi}^*}^G = \frac{g(\hat{\xi}^*)\hat{\xi}^*}{G(\hat{\xi}^*)}$ denotes the elasticity of the survival probability with respect to the cutoff value for liquidity shocks $\hat{\xi}^*$. Since we measure TFP-growth by the part of output growth which is not explained by the growth of the input factors, it follows that productivity growth for the basic technology is:

$$\widehat{TFP^k} \;=\; \widehat{y^k} - \alpha^k \widehat{k} - (1-\alpha^k)\widehat{l^k} = \widehat{\mathcal{A}},$$

where the first equality is an implication of the definition (in terms of subaggregates for the respective intermediate goods) of TFP as the Solow residual. Similarly, for the advanced technology, we get:

$$\widehat{TFP^z} \;=\; \widehat{y^z} - \alpha^z \widehat{z} - (1-\alpha^z)\widehat{l^z} = \widehat{\mathcal{V}} + \omega^G_{\hat{\xi}^*}\widehat{\hat{\xi}^*}$$

From these equations, we can deduce overall TFP-growth as the weighted sum of productivity growth of the different technologies. Specifically, from (3.11), aggregate output is given by a CES aggregation of the intermediate outputs produced with the different technologies. Aggregate output growth can then be expressed as the composite of technology-specific growth rates:

$$\widehat{y} = \zeta^{\frac{1}{\rho}} \left(\frac{y^k}{y}\right)^{\frac{\rho-1}{\rho}} \widehat{y^k} + (1-\zeta)^{\frac{1}{\rho}} \left(\frac{y^z}{y}\right)^{\frac{\rho-1}{\rho}} \widehat{y^z} = \omega^y_{yk}\widehat{y^k} + \omega^y_{yz}\widehat{y^z}$$

Hence, combining the expression for aggregate output growth with the results for the intermediate output growth rates, aggregate TFP-growth, i.e. innovations to aggregate output growth which cannot be attributed to changes in capital or labor growth, is measured as:

$$\begin{aligned}
\widehat{TFP} = \widehat{\mathcal{T}} \;&=\; \widehat{y} - \omega^y_{yk}\left(\alpha^k\widehat{k} + (1-\alpha^k)\widehat{l^k}\right) - \omega^y_{yz}\left(\alpha^z\widehat{z} + (1-\alpha^z)\widehat{l^z}\right) \\
&=\; \omega^y_{yk}\widehat{TFP^k} + \omega^y_{yz}\widehat{TFP^z} \\
&=\; \omega^y_{yk}\widehat{\mathcal{A}} + \omega^y_{yz}\left(\widehat{\mathcal{V}} + \omega^G_{\hat{\xi}^*}\widehat{\hat{\xi}^*}\right)
\end{aligned}$$

C.3 Calibration and data sources

To operationalize the calibration exercise, functional forms need to be specified. As to household preferences, we postulate a Cobb-Douglas utility function in consumption c^H and leisure $(1-h^H)$:

$$u(c^H, h^H) = \frac{1}{1-\sigma}\left[(c^H)^\mu (1-h^H)^{1-\mu}\right]^{1-\sigma}, \qquad 0 < \mu < 1$$

The production functions describing the two available technologies have already been introduced with a Cobb-Douglas specification. Thus, it only remains to specify the adjustment cost function associated with variations in the technology-specific capital stocks $i = k, z$:

$$\Phi(i_t, i_{t+1}) = \frac{\phi}{2} i_t \left(\frac{i_{t+1} - i_t(1+\gamma)}{i_t}\right)^2,$$

which guarantees that, as the economy grows, the average resources spent in terms of adjustment costs remain constant and that along a balanced growth path these costs are zero. Finally, the exogenous productivity shocks to intermediate goods production are assumed to obey the following autoregressive process:

$$\begin{pmatrix} ln(\mathcal{A}_t) \\ ln(\mathcal{V}_t) \end{pmatrix} = \begin{pmatrix} \rho_a & 0 \\ 0 & \rho_v \end{pmatrix} \begin{pmatrix} ln(\mathcal{A}_{t-1}) \\ ln(\mathcal{V}_{t-1}) \end{pmatrix} + \begin{pmatrix} 0 \\ (1-\rho_v)ln\,(\chi) \end{pmatrix} + \begin{pmatrix} \epsilon_{a,t} \\ \epsilon_{v,t} \end{pmatrix}$$

$$\begin{pmatrix} \epsilon_a \\ \epsilon_v \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_a^2 & \sigma_{av} \\ \sigma_{av} & \sigma_v^2 \end{pmatrix} \right),$$

where χ is a measure of the productivity gap between the advanced sector and the basic sector along the balanced growth path.

The parameters we set beforehand are the coefficient of relative risk aversion $\sigma = 2$ as well as Ω and η which determine the relative importance of the entrepreneurs in the economy with respect to their labor supply and their accumulated wealth; in view of the parametrizations employed in the literature, we set $\Omega = 0.95$ and $\eta = 0.97$.[5] As to the parameters determined from the data, we first resort to relevant time series for the US at quarterly frequency (1959:1-2006:2) which were obtained from the Bureau of Economic Analysis (2006) and the Bureau of Labor Statistics (2006). Specifically, we set $\gamma = 0.0037$ to match the average growth rate of real output per hour worked over our sample of 0.37% per quarter and $\beta = 0.98$ to match the average implied real interest rate - the difference between the nominal interest rate and the rate of inflation - of 2.7% over this sample. The preference parameter $\mu = 0.167$ is calibrated to be on average consistent with the consumption-leisure FOC (C.3), while $\alpha^k = \alpha^z = \alpha = 0.31$ are set to match the labor share of income.[6] Finally, $\delta = 0.0112$ is pinned down such as to match the average consumption of fixed capital. The investment adjustment cost parameter $\phi = 12.5$ is determined such as to match the empirical volatility of aggregate investment of 5.60%.

The critical parameter for our analysis is the fraction θ of the firms' wage bill that needs to be paid in advance because it pins down the quantitative importance of liquidity relative to overall short-term credit. We calibrate θ using the information on firms' balance sheets reported in Opler et al. (1999). There, the sample mean (median) of liquid assets over total assets net of liquid assets is at 18% (6%), while total (= short-term plus long-term) leverage is at 28% (25%). These numbers imply a ratio of liquid assets to total debt of 0.54 (0.23). The corresponding model statistic is $\frac{D}{D+\theta WL}$; we choose $\theta = 0.25$ such that the steady state value for this expression is at 0.36, falling in between the empirical reference statistics.

[5] Compare e.g. Bernanke, Gertler and Gilchrist (1999) and the references therein.

[6] The restriction $\alpha_k = \alpha_z$ is imposed due to the lack of informative data. Note also that we treat entrepreneurs' wage earnings as part of the overall labor earnings and that the labor share needs to be adjusted since, due to the firms' advance financing requirement, part of the income is used to pay interest; specifically, we exploit the following steady state relation: labor share $= \frac{(1-\alpha)}{[1+\theta(\tilde{R}-1)]}$.

The composition of economic activity is mainly determined by the parameters ρ, ζ and χ, which we calibrate from industry data, as well as by the agency cost parameter b and the moments μ_ξ, σ_ξ of the liquidity shock distribution $G(\cdot)$, which is assumed to be lognormal. The parameters $b = 0.15$, $\mu_\xi = -0.75$, $\sigma_\xi = 0.75$ are jointly calibrated such as to generate a steady state with (i) an advanced project survival rate of 83% (corresponding to a failure rate of 4.6% across both technologies). In order to pin down the parameters ρ and ζ, we recover estimates for these parameters using annual industry-level data from the UNIDO (2002) industry database covering the period 1963-2000. These data provide disaggregate information on value added and output prices at industry level according to the Standard Industrial Classicication (SIC) system; we drop the government and the financial sector as well as industries with missing data and are left with 36 industries (see Table 7). We organize these remaining industries into two subaggregates, whereby the sorting criterion is the standard deviation of each industry's growth rate of value added over time. We interpret these subaggregates as the two intermediate production technologies in our model economy and use the associated relative prices to infer the parameters of interest from (3.12). In particular, from total differentiation of these relative demand schedules, one obtains (with hats denoting relative changes):

$$\widehat{\left(\frac{y^i}{y}\right)} = -\rho \widehat{\left(\frac{P^i}{P}\right)}$$

This allows to isolate the elasticity of substitution $\rho = 1.66$. Now, (3.12) and (3.14) can be solved for the relative sectoral weights $\zeta = 0.73$ and $(1 - \zeta) = 0.27$ as well as the elasticities of aggregate output with respect to the sectoral intermediate output levels:

$$\omega^y_{yk} = \zeta^{\frac{1}{\rho}} \left(\frac{y^k}{y}\right)^{\frac{\rho-1}{\rho}} \qquad \text{and} \qquad \omega^y_{yz} = (1-\zeta)^{\frac{1}{\rho}} \left(\frac{y^z}{y}\right)^{\frac{\rho-1}{\rho}}$$

The productivity difference parameter across the two subaggregates is estimated from the respective value added data as $\chi = 1.26$. Similarly, we exploit the time series properties of value added in the two industrial subaggregates in order to parametrize the relevant stochastic processes for technology. We directly infer $\rho_a = 0.79$, $\rho_v = 0.66$ and $\rho_{av} = 0.67$; the volatility parameters σ_a and σ_v are also estimated from the relevant value added data, but adjusted (keeping relative values constant) to be consistent with the volatility of aggregate TFP, which yields $\sigma_a = 0.0075$ and $\sigma_v = 0.0111$. Finally, $\rho_j = 0.35$ and $\sigma_j = 0.0069$ are calibrated from the empirical process for $M2$.

Data sources:

- Section 3.3: CPI inflation and GDP deflator, real GDP, government and private investment shares are all from the Bureau of Economic Analysis (2006);

the own rate of M2 and Moody's Seasoned Aaa Corporate Bond Yield are from the Federal Reserve Bank of St. Louis (2006); the financial controls are from Beck and Levine (1999).

- Section 3.6.1: The growth rate of value added at 3-digit SIC level is from the UNIDO (2002) industrial statistics database - the data are identical to the OECD-STAN (2003) data for the US; the other data sources are as for Section 3.3.
- Section 3.6.2: The firm-level data employed on top of the aggregate data come from the Compustat database; apart from the larger period of time covered, they coincide with the data employed by Opler et al. (1999).

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