

Essays on Macroeconomics

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Abstract

This thesis consists of three self-contained essays on macroeconomics.

Inattentive Consumers in General Equilibrium. This paper explores the effects of heterogeneity in planning propensity on wealth inequality, asset prices and welfare. I consider a simple model economy populated by "attentive" and "inattentive" agents. Attentive agents plan their consumption, savings, or stock holdings period by period, while inattentive ones plan every other period. In partial equilibrium with fixed asset prices, inattentive consumers face more uncertainty and save more for precautionary reasons. In general equilibrium, their savings are positively correlated with bond prices, but inattentive consumers still accumulate more wealth. Moreover, asset prices are much more volatile than in a representative agent model with full attention, because they must induce attentive consumers to voluntarily bear the entire burden of adjusting to aggregate shocks. In a simple two-period portfolio choice model driven by uncertain asset returns, however, infrequent revisions of portfolios can produce the opposite result: inattentive investors accumulate less wealth.

Monetary Regime Change and Business Cycles. This paper analyzes how changes in monetary policy regimes can influence the economic dynamics in a small open economy. We estimate a DSGE model on Swedish data incorporating the change in 1993 from an exchange rate targeting to an inflation targeting regime. For each regime, we estimate the behavior of the monetary authority and the relative contribution to the business cycle of structural shocks. The results confirm that monetary policy indeed mainly reacted to exchange rate movements in the target zone and to inflation in the inflation targeting regime. A variance decomposition analysis suggests that devaluation expectations were the main source of volatility in the target zone period. In the inflation targeting period, labor supply and preference shocks become relatively more important. Shocks to foreign variables were in general more destabilizing under the target zone regime than under inflation targeting.

Do Central Banks React to House Prices? Recently, house prices have undergone major fluctuations in many industrialized economies, which has drawn the attention

of policymakers and academics towards the developments in housing markets and their implications for monetary policy. In this paper, we ask whether the U.S. Fed, the Bank of Japan and the Bank of England have reacted to house price inflation. We study the responses of these central banks by estimating a structural model for each country where credit constrained agents borrow using real estate as collateral. The main result is that house price movements did play a separate role in the U.K. and Japanese central bank reaction functions in the last years, while they did not in the U.S.

To Martin

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As a monetary economist, I like to think that money matters. Financial support from the Royal Swedish Academy of Sciences, Widar Bagge's, Kock-Lindberg's and Handelsbanken's Research Foundations is gratefully acknowledged

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Stockholm, October 2007

Daria Finocchiaro

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Chapter 1

Introduction

This thesis consists of three self-contained essays that deal with different aspects of macroeconomics. The first essay is a theoretical study of how differences across people in their propensity to plan affect wealth accumulation and asset prices. The second and third essays are empirical studies. The second studies how a regime change in monetary policy altered the determinants of the Swedish business cycles, while the third essay addresses the question of whether the central banks in the U.S., U.K. and Japan have reacted to house price inflation in the last twenty years. Even though the topics of the three chapters are rather different, the essays still share some important common features.

Modeling-wise, each of them relies on a microfounded dynamic stochastic general equilibrium (DSGE) model. Macroeconomics has changed substantially after 1976, when Lucas published his influential paper on the "Lucas critique".¹ He pointed out that the estimated relations in reduced form macroeconomic models were influenced by the particular economic policy rule in use. Hence, such models could not be used for policy analysis, as rational agents would update their expectations, and change their behavior, in response to changes in policy rules. A new generation of macroeconomic models immune to the Lucas critique was born. Key ingredients of this emerging literature were rational expectations and sound microfoundations, i.e., individual behavior is derived from an explicit optimization problem. The models presented in this thesis satisfy this requirement.

The economies described in chapter 2 and chapter 4 deal with heterogenous, rather than representative, agents. A recent strand of the macroeconomic literature has studied the effects of departures from the representative agent paradigm on

¹See Lucas (1976)

phenomena such as asset prices, welfare and wealth inequality. The model in chapter 2 proceeds along the lines of this literature and studies an economy where some agent plan their portfolios or consumption more frequently than others; while the model in chapter 4 contains agents who differ in their discounting of the future.

The last two chapters follow the new Keynesian tradition and handle micro-founded models with nominal rigidities stemming from monopolistic competition on the supply side.

Methodologically, the models are solved with numerical methods and, in the last two chapters, structurally estimated with methods that rely on Bayesian inference. As emphasized in Sims (1995), a stochastic model generates a whole distribution rather than a single statistic. Bayesian inference provides a framework for dealing with the "real" nature of DSGE models, Markov Chain Monte Carlo (MCMC) methods make such inference computationally feasible because they allow us to simulate the entire likelihood and measure different moments. The pioneering work by Smets and Wouters (2003) has shown the advantages of using Bayesian inference to estimate a medium-scale DSGE model. Chapter 3 and 4 follow in their steps.

In what follows, I briefly summarize the content and results of each chapter.

Inattentive Consumers in General Equilibrium. Chapter 2 departs from a traditional saving model by introducing heterogenous planning propensities among consumers. The aim of the essay is to analyze what happens to wealth accumulation and asset prices when a fraction of the population infrequently plan its consumption, savings or stock holdings. Recent empirical work on planning behavior² has shown a widespread lack of planning among young workers, as well as people close to retirement. Moreover, even though the phenomenon is prevalent among households with low income and education, some highly educated individuals also have a low propensity to plan and only plan infrequently³. According to the same empirical literature, infrequent planning might explain wealth heterogeneity among households with otherwise similar characteristics, where households that plan infrequently also hold lower wealth.

In theory, the propensity to plan could affect wealth along different channels. For example, infrequent planners may accumulate less wealth because they follow myopic (rule of thumb) behavior, because they have time inconsistent preferences, or

²See Lusardi (2003).

³In the sample of Ameriks, Caplin, and Leahy (2003), the majority of respondents holds a Master's or higher university degree.

because they make different investment choices. The evidence in Lusardi (2003) hints that planning indeed affects portfolio choice and that infrequent planners choose less risky and profitable portfolios. On the other hand, the results in Ameriks, Caplin, and Leahy (2003) and Venti and Wise (2000) suggest that differences in saving rather than financial choices are at the origin of wealth dispersion among households with the same characteristics. Present bias preferences, for example, could turn infrequent planners into overspenders.

My essay shows that in a simple model economy populated by "attentive" and "inattentive" agents, where the latter plan their consumption only every other period, inattentive consumers accumulate more wealth. In general equilibrium, inattentiveness affects wealth inequality through two different channels, which work in opposite directions. It increases wealth accumulation of the inattentive group via a precautionary savings motive and decreases wealth accumulation via negative price effects. Inattentive consumers face more uncertainty about the future, since their consumption becomes predetermined for some time, which induces them to save more for precautionary reasons, but their bond holdings are negatively correlated with asset returns. Moreover, asset prices are much more volatile in my model than in a representative agent model with full attention. Intuitively, prices have to fluctuate more, because they must induce attentive consumers to voluntarily bear the entire burden of adjusting to aggregate shocks.

When the source uncertainty is asset returns rather than income infrequent revision of portfolios produces the opposite result, consistently with the empirical literature: inattentive investors accumulate less wealth for reasonable levels of risk aversion. In this case, more uncertainty pushes the inattentive group towards less risky and less profitable portfolio choices. Also in this case does the model generate highly volatile bond prices and high risk premia.

Monetary Regime Change and Business Cycles. Chapter 3, coauthored with Vasco Cúrdia, studies the impact of a monetary regime change on the business cycle of a small open economy. After the breakdown of the Bretton Woods system in 1973, we have witnessed collapses of many fixed exchange rate systems. The crash of the exchange rate system temporarily left monetary policy without an anchor. However, price stability soon became the new goal and inflation targeting the way of achieving it. The experience in Finland, England and Sweden, among others, illustrates how central banks have successfully rebuilt their credibility through the announcement of explicit inflation targets. After one decade of inflation targeting,

it is time to evaluate the relations between different monetary policy regimes and macroeconomic stabilization and assess the driving forces behind the business cycles under different regimes.

In this essay, we look at Sweden, a good example of a small open economy that experienced such a monetary regime change. Price stability has been the overall target of monetary policy in Sweden only since January 1993, when the Riksbank announced an explicit inflation target of 2% (with $\pm 1\%$ bands). Previously, for almost 120 years⁴, Sweden had maintained a fixed (or nearly fixed) exchange rate abandoned on the 19th of November of 1992 when, after the dramatic and unsuccessful attempt at defending the currency, the Riksbank decided to abandon that exchange rate regime and, shortly thereafter, announced the adoption of an inflation targeting regime.

To shed light on the consequences of this regime change, we estimate a small open economy DSGE model with imperfect exchange rate pass-through on Swedish data. Our main purpose is to analyze how the economic dynamics changed from one regime to the other. Consistently with a priori expectations, in the target zone, the authorities mainly reacted to exchange rate deviations from central parity, while under inflation targeting, they exploited the flexibility to react to different shocks. The estimated coefficients of the Riksbank's interest rate rules show that in the target zone, the central bank was highly responsive to the exchange rate, while during inflation targeting mainly reacted to inflation. Foreign shocks generated generally stronger responses under the target zone than under inflation targeting, while the opposite was true for domestic shocks. In the target zone period, devaluation expectations had a predominant role in generating economic volatility. The sizable contribution of this shock to business cycle fluctuations supports casual observation and the earlier findings in Lindberg, Söderlind, and Svensson (1993), which argue that devaluation rumors were circulating on several occasions during the target zone period (in addition to three actual devaluations).

Do Central Banks React to House Prices? Chapter 4, coauthored with Virginia Queijo von Heideken, asks whether house prices entered directly in the monetary policy rule of the U.S. Fed, the Bank of Japan and the Bank of England in the last twenty years.

⁴In September 1931, Sweden abandoned the Gold Standard and became the first country that adopted explicit price level targeting. The Swedish krona was left free to float until July 1933 when the Riksbank decided to enter the Sterling block, thus pegging the krona to the British pound. (cf. Berg and Jonung (1998))

Real house prices have risen by more than 30% in the U.S. since 1995 while in the U.K., they peaked in 1989, had lost almost 40% of their value by 1995, and have continuously increased since then. The experience of Japan is also dramatic. Property prices increased almost 40% in the five years before 1991 and have fallen since then. At the same time, there has been a substantial increase in household indebtedness. Since borrowing for housing constitutes the largest part of households' debt in most countries, the increase in indebtedness has exposed the overall macroeconomic situation even more to house price fluctuations. The observed boom-bust cycles in house prices have made both academic economists and practitioners interested in developments in real estate markets and their impact on economic activity and financial stability.

To address the question whether the three central banks have reacted to house prices, we structurally estimate a model where credit-constrained agents borrow against their housing, thereby amplifying business cycle fluctuations. In this way, we can deal with the difficult endogeneity problems that would arise if we were to estimate a Taylor rule with asset prices in a single equation context. The main contributions of the essay are twofold. First, we add to the debate on monetary policy and asset prices by performing a rigorous structural estimation and formal model comparison. Using such an approach, we can also investigate the business cycle implications of a central bank reacting to house prices. Second, we contribute to the scarce empirical literature on estimated DSGE models for the U.K. and Japan, using the estimated models to identify the shocks behind the business cycles of these two economies. The main result of the essay is that house price movements did play a separate role in the reaction functions of central banks in the U.K. and Japan over the sample period, while they did not in the U.S. This result is robust to different specifications of the estimated monetary policy rule. Moreover, our results show a lower degree of price and wage stickiness in Japan and the U.K. than in the U.S. In all three countries, supply shocks play a major role in explaining business cycle fluctuations.

Chapter 2

A General Equilibrium Model with Inattentive Consumers^{*}

1 Introduction

Traditional saving models assume that people formulate their consumption plans period by period, gathering and processing as much information as they need about the state of the economy without facing any "planning" cost. However, survey evidence suggests that such costs do exist and that they lead to infrequent planning or even complete lack of planning. Furthermore, empirical work on planning¹ finds that not everybody's behavior departs from the assumptions of the standard permanent income/life cycle model: people differ in their propensity to plan.²

In this paper, I try to address both these findings. I focus on heterogeneity in planning and explore the links between propensity to plan, wealth inequality and asset prices in general equilibrium. I assume that agents are heterogeneous only in their propensity to plan: attentive agents plan their consumption, savings or stock holdings period by period, while inattentive ones plan every other period. Then, I study the implications of this assumption in general equilibrium. I show

^{*} For countless discussions, invaluable comments and continuous support, I am deeply indebted to John Hassler, Per Krusell and, my main advisor, Torsten Persson. I also benefited from comments from Marieke Bos, Vasco Cúrdia, Martin Flodén, Ethan Kaplan, Dirk Niepelt, Virginia Queijo von Heideken, Ricardo Reis and seminar participants at the IIES and SITE (Stockholm). I would also like to thank Christina Lönnblad for editorial assistance. Financial support from Handelsbanken's Research Foundations is gratefully acknowledged. The usual disclaimer applies.

¹ Both Lusardi (2006) and Venti (2006) review recent empirical evidence on planning and saving behavior.

² Heterogeneity in planning behavior might arise if planning depends on other people's experience, as individuals learn how to plan from their siblings or their parents, or if planning is related to education, as more educated people have a higher propensity to plan.

that differences in the propensity to plan generate wealth heterogeneity and volatile asset prices.

In a canonical consumption/saving model, wealth heterogeneity can be explained by differences in preferences structures. Differences in discount factors or in risk aversion, for example, might do the job as well as bequest motives. However, recent empirical work by Lusardi (2003) and Ameriks, Caplin, and Leahy (2003), among others, suggests a link between differences in wealth accumulation and propensity to plan. According to this evidence, infrequent planning has an impact on wealth accumulation, thereby causing considerable wealth heterogeneity among households with similar economic and demographic characteristics. More precisely, infrequent planning leads to lower saving and wealth accumulation. But this finding is at odds with the existing literature on infrequent planning: in a partial equilibrium model with fixed interest rates, Reis (2006) shows that consumers who plan infrequently face more uncertainty and save more for precautionary reasons.

In my general equilibrium model, the inattentive group suffers from an adverse correlation between bond prices and savings. By setting a plan for consumption, an inattentive consumer will let her savings automatically adjust to income shocks. In general, she will accumulate more bonds when the bond price is high and reduce her bond holdings when prices are low. This adverse "term of trade effect" could lead to lower wealth. However, this channel does not prevail and even in general equilibrium, when the only source of uncertainty is future income, inattentive consumers still accumulate more wealth.

Turning to asset price implications, inattention generates more volatile and less autocorrelated bond prices as compared to a representative agent model with full attention. In general equilibrium, asset prices must induce attentive consumers to voluntarily bear the entire burden of adjusting to aggregate income shocks, since inattentive agents are unable to do so. Therefore, attentive agents' consumption is more volatile as compared to what they would experience in a world with full attention, but they can trade at more favorable bond prices. I study the welfare consequences for both types of agents and find that the costs of being inattentive are modest and that the attentive group is better off (both compared to a representative agent model with full attention).

Infrequent planning modifies the standard consumption/saving model also in

another important respect: choosing consumption or saving is no longer equivalent. Turning to the problem of an inattentive saver, i.e., an individual who chooses her *savings* every other period, differences in planning times *do not* lead to wealth heterogeneity in general equilibrium with only aggregate shocks. In this set up, both kinds of agents find it optimal to live hand-to-mouth and consume their income period by period. Hence, in equilibrium, bond prices behave as in a model with full attention. This result, which might at first seem surprising, follows trivially from the assumptions that there are only aggregate shocks, that savings are in zero net supply and that agents are homogenous ex ante. Under the same assumptions but with full attention, the representative agent would simply consume her income period by period. Intuitively, inattentive consumers are worse off as compared to the full attention representative agent model. If they infrequently decide upon consumption, savings must adjust at non-planning dates to satisfy the budget constraint, while if they fix savings in advance, they can reach the optimal full attention allocation simply setting their savings equal to zero. In this case, their consumption will fluctuate to satisfy the budget constraint.

Finally, I study the consequences of inattentiveness in a general equilibrium portfolio choice model, where the source of uncertainty is asset returns rather than income. To shed light on the mechanisms behind investment decisions, I analyze a stylized two-period model, where inattentive investors infrequently review their portfolios. In this set-up, infrequent planning can indeed decrease wealth accumulation and it generates large equity premia.

The rest of the paper is organized as follows. Section 2 provides a review of the related literature and Section 3 introduces a simplified two-period model that can be solved analytically. Section 4 presents an infinite-horizon version of the model and Section 5 comments on its comparative statics and dynamics results. Section 6 analyzes the problem of inattentive savers. Section 7 studies the portfolio decisions of inattentive investors in general equilibrium. Section 8 concludes.

2 Literature review

It is not a new idea that the cognitive ability required by the standard rational decision making paradigm may be beyond human capabilities. The pioneering work

by Jacob Marschak and Herbert Simon emphasized that rational choice could be modified to take into account information costs or be abandoned in favor of (Simon's own words) bounded rationality. In recent years, quite a few papers have tried to model the reasons behind deviations from full information/rationality and have analyzed their consequences. But little attention has been given to the implications of these departures from the standard paradigm in general equilibrium. This paper aims at taking a small step towards filling this gap in the context of macroeconomics.

Recently, one branch of the literature has explored the sources of deviations from full information. Sims (2003) and Moscarini (2004) use Shannon's information theory to develop a theory of costly information acquisition. In their framework, information flows are seen as reducing uncertainty, as measured by entropy. They assume information to be transmitted by channels with limited capacity. Incorporating such information capacity constraints in otherwise standard optimization problems, Sims (2003) and Moscarini (2004) let individuals optimally react to external information and choose the accuracy of the signal (rational inattention).³ Their work stresses the role of information frictions as a source of the inertia empirically observed in many macroeconomic series.

In a modification of the permanent income model, Luo (2005) proposes rational inattention as an explanation for the excess sensitivity and the excess smoothness consumption puzzles.⁴ When a capacity constraint enters in a standard consumption saving model, consumption will respond smoothly and with delay to wealth, and consumption changes are predictable by past known income shocks. Reis (2006) reaches similar conclusions in a partial equilibrium consumption/saving model where the introduction of a cost of processing and acquiring information microfounds infrequent planning. When agents rationally choose to only sporadically update their plans, consumption is sensitive to past information, because consumers react to all new information since their last adjustment date. Consumption is also excessively smooth, since only a fraction of the population reacts to income shocks in each period.

A different branch of the literature had focused on the implication of near-

³ As opposed to Sims (2003), in Moscarini (2004)'s work the information rate constraint is met by infrequently observing and processing new information

⁴ According to the findings of Deaton (1987) and Flavin (1993), aggregate consumption is excessively sensitive to past known information and excessively smooth to permanent income shocks.

rationality and infrequent planning, without specifying the rationale behind it. Caballero (1995) explores the consequences of near-rationality, in the Akerlof and Yellen (1985) sense, on aggregate consumption dynamics. According to Caballero (1995), a model where a fraction of the population only occasionally resets its consumption patterns can explain the excess sensitivity and excess smoothness of consumption to wealth innovation. Lynch (1996) considers an OLG model where all individuals make their consumption and portfolio decisions in a staggered way and analyzes the consequence of infrequent planning for the equity premium puzzle. Infrequent planning leads to a reduction in the volatility of aggregate consumption growth and in its correlation with equity return. Gabaix and Laibson (2002) propose a continuous time generalization of Lynch's model that generates effects of a larger magnitude than the discrete-time version. My paper is most closely connected to this strand of literature, since I abstract from planning costs and just postulate that a fraction of the population plans only infrequently. However, it goes further by considering a general equilibrium model with endogenous asset prices.

Mankiw and Reis (2006) analyze a general-equilibrium model where agents are inattentive when setting prices, wages, and consumption. However, to avoid tracking the wealth, Mankiw and Reis (2006) assume that agents can sign an insurance contract ensuring that they all have the same wealth at the beginning of each period. As standard in the new Keynesian literature, they can therefore rely on loglinearization around the non-stochastic steady state of the model to obtain the aggregate equilibrium conditions. In contrast, my paper explicitly takes into account the consequences of infrequent planning on wealth heterogeneity and solves the model with global methods.

In its dealing with wealth heterogeneity, my paper is also related to the vast literature on wealth and income inequality. Krusell and Smith (1998) and Hendricks (2004) among others, link the cross-sectional dispersion and skewness of wealth observed in U.S. data to differences in preferences. In an extension of a stochastic growth model with partially uninsurable idiosyncratic risk, Krusell and Smith (1998) show that a small amount of heterogeneity in discount factors can account for observed wealth inequality. In a modified version of a stochastic incomplete markets life-cycle model (e.g., Huggett (1996)), Hendricks (2004) points out that discount rate heterogeneity can also successfully account for the large wealth inequality ob-

served among households with similar lifetime earnings. Coen-Pirani (2004) studies how differences in risk aversion influence wealth inequality in an endowment economy with two types of Epstein-Zin agents. He shows that when risk aversion and intertemporal substitution are not given by the same parameter, more risk averse individuals might dominate the long-run distribution of wealth. Other studies emphasize the role played by intergenerational links (e.g. Yang (2006)) or "capitalist spirits" (e.g., Francis (2005)) in explaining wealth heterogeneity upon retirement.

Finally, the paper builds on the literature on incomplete markets with heterogeneous agents and aggregate fluctuations (e.g., Den Haan (1996), Krusell and Smith (1997, 1998)), but departs from it by making propensity to plan the only source of heterogeneity.

3 A two-period model of inattention

In this section, I analyze a simplified two-period model that can be solved analytically. The purpose is to illustrate the implications of inattentiveness and disentangle partial equilibrium from general equilibrium effects.

Consider an economy with two kinds of agents who are identical *ex ante*, receive the same stochastic income stream but differ from each other in the timing of their consumption plans. Attentive consumers behave as in a standard consumption/savings model, while inattentive ones must choose period 1 consumption before the income shock in period 1 is realized. Income is only stochastic in period 1, when it can take on two values, $y_H = 1 + \varepsilon$ and $y_L = 1 - \varepsilon$, each with probability $\frac{1}{2}$. In period 2, income is deterministic and normalized to one. Both agents can smooth consumption by saving in a riskless bond b which, in general equilibrium, is in zero net supply. In partial equilibrium, bond prices are fixed to one. For simplicity, it is assumed that utility is logarithmic and discounting is absent.

Consider the problem faced by an attentive consumer (A) in partial equilibrium. Since income is not stochastic in the second period, she does not face any uncertainty and can perfectly smooth the income shock between the two periods:

$$c_1^A = c_2^A = 1 \pm \frac{\varepsilon}{2}. \quad (2.1)$$

Hence, an attentive consumer saves pro-cyclically and her *expected* savings (and

bond holdings) are equal to zero.

Conversely, inattentive consumers (I) make their consumption plan before the income shock is realized and their decisions cannot be made state contingent. Therefore, they must solve the following stochastic problem:

$$\begin{aligned} \max_{c_1^I} \quad & \ln(c_1^I) + E_0 \ln(c_2^I) \\ \text{st :} \quad & c_1^I + b_{2J}^I = y_{1J} \\ & c_2^I = 1 + b_{2J}^I, \quad \text{with } J = H, L \end{aligned}$$

which leads to

$$\begin{aligned} c_1^I &= \frac{3}{2} - \frac{1}{2}\sqrt{1 + 2\varepsilon^2}, \\ c_{2J}^I &= \frac{1}{2}\sqrt{2\varepsilon^2 + 1} + \frac{1}{2} \pm \varepsilon. \end{aligned} \tag{2.2}$$

Inattentive consumers must deal with uncertainty. As is standard in consumption theory, this implies an increase in wealth accumulation for precautionary reasons. Their expected savings are positive and increasing in uncertainty:

$$E(b_2^I) = \frac{1}{2} \left[\sqrt{1 + 2\varepsilon^2} - 1 \right] > 0.$$

Since inattentive agents' consumption is fixed and not state contingent, their savings (and bond holdings) must move pro-cyclically to satisfy the budget constraint ($b_{2H}^I > 0$ and $b_{2L}^I < 0$) and absorb the income shock. Therefore, in partial equilibrium, an inattentive consumer faces a more volatile consumption profile (eq.(2.2)) compared to an attentive consumer who can perfectly smooth the income shock (eq.(2.1)).

In general equilibrium, bond prices must clear the market. A positive (negative) income shock pushes up (down) the demand for savings of both groups. However, inattentive consumers have a higher marginal propensity to save, since their savings respond one for one to the income shock (as consumption is predetermined). It follows that market-clearing prices must be pro-cyclical:

$$q_{1L} = \frac{1}{3}\sqrt{48\varepsilon^2 + 1} - 3\varepsilon + \frac{2}{3}, \tag{2.3}$$

$$q_{1H} = 3\varepsilon + \frac{1}{3}\sqrt{48\varepsilon^2 + 1} + \frac{2}{3} \Rightarrow \tag{2.4}$$

$$q_{1H} > q_{1L}$$

Since bonds are in zero net supply, these results imply that inattentive consumers save when interest rates are low and borrow when interest rates are high. This "price effect" on their wealth might, in principle, overturn the precautionary saving effect. However, a closer inspection of inattentive agents' expected bond holdings reveals that this is not the case, at least not in this simplified version of the model:

$$E(b_2^I) = \frac{1}{2} \frac{\varepsilon + \frac{1}{6}\sqrt{48\varepsilon^2 + 1} - \frac{1}{6}}{3\varepsilon + \frac{1}{3}\sqrt{48\varepsilon^2 + 1} + \frac{2}{3}} + \frac{(\frac{1}{6}\sqrt{48\varepsilon^2 + 1} - \varepsilon - \frac{1}{6})}{2(\frac{1}{3}\sqrt{48\varepsilon^2 + 1} - 3\varepsilon + \frac{2}{3})}. \quad (2.5)$$

Inattentive consumers always accumulate more bonds than attentive ones.⁵

When the economy is more volatile, the effects of inattentiveness on wealth accumulation are magnified and inattentive consumers accumulate even more wealth. This allows them to achieve better consumption smoothing so that, on average, c^I is less volatile than c^A . As a consequence, inattentiveness also has an impact on the volatility of bond prices, since prices must induce attentive consumers to bear the whole burden of a more volatile consumption profile. In an economy with the same structure as the model, but with full attention of all consumers, the representative agent consumes her income period by period and bond prices are equal to:

$$q_{1H} = 1 + \varepsilon, \quad q_{1L} = 1 - \varepsilon \quad (2.6)$$

Comparing (2.6) to the results in (2.3) and (2.4), we see that inattentiveness makes bond prices more volatile and, on average, higher than in a model with full attention. Still, inattentive consumers are always worse off as compared to attentive ones. Moreover, the difference in welfare of the two groups is increasing in income volatility.

To summarize, inattentiveness affects wealth inequality in opposite directions through two different channels. It increases the wealth accumulation of the inattentive group via precautionary savings motives and decreases it via negative price effects. In the two-period model, the first effect prevails. Moreover, inattention makes bond prices more volatile than they would be in a model with full attention.

Although the two-period model offers a simple and tractable set-up and sheds

⁵ $E(b_2^I) > 0$ in (2.5).

light on certain mechanisms, it is worthwhile to turn to an infinite horizon to quantify the magnitudes of these effects. The next sections will be devoted to developing a more general model where inattentive consumers make consumption plans every other period and let savings absorb income shocks. Hence, they repeatedly "suffer" the negative effect of prices on their suboptimal savings.

4 Infinite horizon and AR(1) income shocks

Consider an incomplete markets economy with infinite horizon and aggregate uncertainty as in Den Haan (1996), but modified to introduce heterogeneity among consumers only in the frequency of their consumption plans. More precisely, attentive consumers (A) behave as in a standard model, choosing consumption and saving plans at the same point in time. Inattentive consumers (I) plan consumption every other period and let savings absorb income shocks. By looking at two groups of agents only, we can characterize the cross-sectional distribution of wealth by the average bond holdings of one of the two groups.

The attentive group has mass α and total population size is normalized to one. Each household is endowed with income y , which follows an $AR(1)$ process, and can smooth its consumption by trading a risk-free one-period bond b , in zero supply, at price q . To rule out equilibria which admit unbounded borrowing or Ponzi schemes, it is assumed that agents can go short in bonds only up to an exogenous limit, \underline{b} .⁶ All agents are price takers in the bond market. The set of relevant state variables will differ between planning and non-planning dates. At non-planning dates, consumption of the inattentive group is predetermined and it affects utility so that it will enter the policy functions as a state variable.

Attentive consumers plan period by period, solving the following problem:

$$V^{L,A}(b_t^A, B_t^A, s_{L,t}) = \text{Max}_{c_t, b_t} \{U(c_t^A) + \beta EV^{L,A}(b_{t+1}^A, B_{t+1}^A, s_{L,t+1})\}$$

$$\text{st. } c_t^A + q_t(B_t^I, s_{L,t})b_{t+1}^A = y_t + b_t^A,$$

$$b_{t+1}^A \geq \underline{b}, \quad L = \{NP, P\},$$

⁶ In the calibration, I chose a level for the debt limit large enough so that the constraint is hardly ever binding.

where B_t^A represents the average bond holding of the attentive group, $s_{NP} = \{y, c^I\}$, $s_P = \{y\}$, $V^{P,A}$ is the value function in planning periods, $V^{NP,A}$ is the value function in non-planning periods and utility is CRRA $\left(U(c) = \frac{c^{1-\mu}}{1-\mu}\right)$.

A standard Euler equation applies:

$$q_t(B_t^I, s_L) [c_{i,t}^A(B_t^A, b_t^A, s_L)]^{-\mu} = \beta E [c_{i,t+1}^A(B_{t+1}^A, b_{t+1}^A, s_L)]^{-\mu}. \quad (2.7)$$

Moreover, in equilibrium, individual policy functions are consistent with the aggregate policy functions for the group:

$$c_i^A(b^A, B^A, s_L) = C_i^A(B^A, s_L).$$

Suppose now that inattentive consumers plan every other period. Then in t they plan consumption today and tomorrow while they remain inattentive during period $t+1$. The problem of an inattentive consumer in planning periods will therefore be:

$$\begin{aligned} V^{P,I}(b_t^I, B_t^I, s_{i,t}) &= \underset{c_t^I, c_{t+1}^I}{Max} \left\{ U(c_t^I) + \beta EV^{NP,I}(b_{t+1}^I, B_{t+1}^I, s_{NP,t}) \right\} \quad (2.8) \\ st : c_t^I + q_t(B_t^I, s_{P,t}) b_{t+1}^I &= y_t + b_t^I, \\ b_{t+1}^I &\geq \underline{b}, \quad b_{t+2}^I \geq \underline{b}. \end{aligned}$$

While, in a non-planning period, it is:

$$\begin{aligned} V^{NP,I}(b_t^I, B_t^I, s_{NP,t}) &= U(c_t^I) + \beta EV^{P,I}(b_{t+1}^I, B_{t+1}^I, s_{P,t+1}) \quad (2.9) \\ c_{t+1}^I + q_{t+1}(B_{t+1}^I, s_{NP,t+1}) b_{t+2}^I &= y_{t+1} + b_{t+1}^I. \end{aligned}$$

We can rewrite the problems⁷ in (2.8) and (2.9) in a more compact form,

$$\begin{aligned} V^{P,I}(b_t^I, B_t^I, s_{i,t}) &= \underset{c_t^I, c_{t+1}^I}{Max} \left\{ \begin{array}{l} U(c_t^I) + \beta U(c_{t+1}^I) + \\ \beta^2 EV^{P,I}(b_{t+2}^I, B_{t+2}^I, s_{P,t+2}) \end{array} \right\} \quad (2.10) \\ st : c_t^I + q_t(B_t^I, s_{P,t}) b_{t+1}^I &= y_t + b_t^I, \\ c_{t+1}^I + q_{t+1}(B_{t+1}^I, s_{NP,t+1}) b_{t+2}^I &= y_{t+1} + b_{t+1}^I, \end{aligned}$$

⁷ The choice of c_{t+1}^I is contingent on the information available in t , which implies that $E_t U'(c_{t+1}^I) = U'(c_{t+1}^I)$

$$b_{t+1}^I \geq \underline{b}, \quad b_{t+2}^I \geq \underline{b}.$$

From (2.10), it is possible to derive the following set of first-order and envelope conditions:

$$q_t^P [c^{I,P}(b_t^I, B_t^I, s_{P,t})]^{-\mu} = \beta^2 E \frac{1}{q_{t+1}^{NP}} [c^{I,P}(b_{t+2}^I, B_{t+2}^I, s_{P,t+2})]^{-\mu} \quad (2.11)$$

$$q_t^P [c^{I,P}(b_t^I, B_t^I, s_{P,t})]^{-\mu} = \beta [c^{I,NP}(b_{t+1}^I, B_{t+1}^I, s_{NP,t+1})]^{-\mu}. \quad (2.12)$$

By consistency, in equilibrium (2.11) and (2.12) become:

$$q_t^P [c^{I,P}(B_t^I, s_{P,t})]^{-\mu} = \beta^2 E \frac{1}{q_{t+1}^{NP}} [c^{I,P}(B_{t+2}^I, s_{P,t+2})]^{-\mu} \quad (2.13)$$

$$q_t^P [c^{I,P}(B_t^I, s_{P,t})]^{-\mu} = \beta [c^{I,NP}(B_{t+1}^I, s_{NP,t+1})]^{-\mu}. \quad (2.14)$$

As in Reis (2006), the solution implies that the consumption of inattentive consumers follows a deterministic path between t and $t+1$, (eq. (2.14)), but a stochastic Euler equation between t and $t+2$ (eq. (2.13)), i.e., between the planning dates.

Finally, the model is closed with the usual market clearing conditions:

$$\alpha b^A + (1 - \alpha) b^I = 0$$

$$\alpha c^A + (1 - \alpha) c^I = y.$$

5 Results

In the numerical implementation of the model, the income process is approximated by a three-state Markov chain, as in Christiano (1990). In the basic case, the mean of the process is normalized to one, the unconditional standard deviation is 2% and the autocorrelation coefficient is 0.9. The discount factor is calibrated at 0.94, so that one period in the model corresponds to one year in the data. The degree of risk aversion is equal to 1.5 and the dimension of the attentive group, α , is equal to $\frac{1}{2}$. The first column in Table 2.1 summarizes the parameters in the basic case.

The solution to the model is a consumption rule for inattentive consumers at planning dates and two pricing rules, at planning and non-planning dates, as a

function of the states, which satisfy the system of Euler equations given by (2.7), (2.13) and (2.14).⁸ Finding this solution requires us to solve a system of functional equations over a continuous space. Because it is impossible to find closed-form solutions for these functions, the model is solved numerically using collocation methods.

As described in Miranda and Fackler (2002), collocation methods transform the problem into a system of non-linear equations that must be satisfied on a finite number of points rather than over the entire domain of the state space. After approximating the policy functions with linear splines, I solve the system of functional equations at the collocation nodes using Newton methods.

To get a good starting point for the algorithm, the model is first solved in the deterministic case. Then, I use an iteration algorithm, stepwise increasing the variance of the income shock and using the solution of the previous iteration as a starting point for the next.

Inattentiveness introduces an additional computational challenge. In non-planning periods ($t + 1$), the price function depends on two continuous state variables, bond holdings of inattentive consumers (b_{t+1}^I) and their predetermined consumption (c_{t+1}^I), as well as the discrete variable y_{t+1} . To simplify the problem and make the solution algorithm more efficient, I note that, in equilibrium, c_{t+1}^I is a function of last period's bond holdings b_t^I and income shock y_t and that b_{t+1}^I is also determined by y_t and b_t^I . Therefore, y_t , b_t^I and y_{t+1} constitute a sufficient state for the price function q_{t+1} at non-planning dates along the equilibrium path.⁹

From the decision rules resulting from the above computations, I obtain the stationary distribution of wealth by following the approach described in Young (2004).¹⁰ Moreover, I simulate the economy for 100,000 periods to study the times series properties of my model and evaluate the welfare costs associated with inattentiveness. The next subsections describe these results, which are summarized in Table 2.2.¹¹

⁸ The consumption rule for the attentive group can then be recovered by the market clearing conditions.

⁹ See Appendix 2.A for a more detailed description of the solution algorithm.

¹⁰ To discretize the state space, I used the matlab routine `locate.m` created by Paul Klein.

¹¹ Table 2.2 reports the ratio of the sample mean of individual consumption to the sample mean of aggregate output.

5.1 Inattentiveness in general equilibrium

As in a standard heterogeneous agents model (e.g. Den Haan (1996)), borrowing constraints and prudence motives generate a consumption function that is concave and increasing in wealth. This is also true for inattentive consumers as shown in Figure 2.1, which plots the consumption of inattentive agents as a function of their aggregate bond holdings (for equilibrium prices).

To shed further light on the results, Figures 2.2 and 2.3 illustrate the saving behavior of an inattentive consumer by graphing her bond accumulation as a function of initial bond holdings, in planning (t) and non-planning periods ($t + 1$).¹²

First, analyze Figure 2.2. Consider a planning date when there is no cross-sectional dispersion in wealth so that both agents hold zero assets: $b_t^I = 0$ in the figure. As in the two-period example of Section 3, even if both groups receive the same income shock, inattentive consumers face more uncertainty since they pre-determine future consumption. This induces them to save more in planning periods, for every realization of the shock ($b_{t+1}^I - b_t^I > 0, \forall y$ if $b_t^I = 0$), for precautionary reasons.

Next, consider Figure 2.3. At a non-planning date, one must distinguish between high and low realization of the income shock. For a good realization of the income shock (right panel), both agents would like to save in anticipation of future declines of income. However, the marginal propensity to save of the inattentive group is higher than that of the attentive group, since they fixed their consumption one period in advance. Hence, their savings increase to satisfy the budget constraint and bond prices rise to keep the market in equilibrium. The opposite is true for a bad realization of the income shock (left panel). In that case, inattentive agents save less than attentive ones and bond prices decrease to clear the market.

Thus, as in the two-period model, inattention magnifies the pro-cyclicality of bond prices and makes inattentive consumers' savings behavior positively correlated with bond prices, while the opposite is true for attentive ones. A similar argument holds towards the lower end of wealth. In non-planning periods, the inattentive group accumulates bonds when income and bond prices are high, while it decumulates bonds when income and bond prices are low.

¹² For illustration purposes, these figures are plotted over a smaller grid for b_t^I . The same graphs plotted over the entire grid ($b_t^I \in [-2, 2]$) are available upon request.

Above a certain threshold for initial bond holdings, an inattentive consumer is so rich that the prudence motive for wealth accumulation fades out. At the same time, prudence motives are strong for an attentive agent because $b^A = -b^I$. This implies that the attentive group is now willing to pay a high price in order to save in good periods and decrease savings in bad periods.

Which of the two mechanisms, precautionary saving or price effects, prevails with infinite horizon? The long-run wealth distribution, plotted in Figure 2.4, shows that even in the more general version of the model with an infinite horizon, the saving effect still prevails and the inattentive group accumulates on average more wealth than the attentive one. The results thus resemble the partial equilibrium results in Reis (2006). Note that the two mechanisms highlighted above are, in fact, connected. The stronger is the precautionary saving motive, the more the inattentive group is willing to trade at unfavorable prices.

To evaluate the effects of inattentiveness on asset prices, first consider an economy populated by a continuum of representative agents with full attention. Absent idiosyncratic shocks, in such an economy, everybody lives hand-to-mouth consuming her income period by period. In this case, bond prices are pinned down by the representative agent's Euler equation:

$$q_t = \beta y_t^\mu E_t y_{t+1}^{-\mu}.$$

In the benchmark case, when $\mu = 1.5$, $\rho_y = 0.9$, and $\sigma_y = 0.02$, this would imply bond prices with a standard deviation of 0.003 and an autocorrelation coefficient of 0.90. As shown in Table 2.2, the presence of inattentive consumers makes prices three times more volatile, with standard deviation 0.01, and only a sixth as autocorrelated, with autocorrelation coefficient 0.14. Asset price volatility stems from the fact that bond prices must induce attentive agents to voluntarily bear the entire adjustment burden, since the inattentive ones are unable to react to income shocks.

Being inattentive obviously alters the ability of consumption smoothing. The first column in Table 2.2 reports some sample moments from the simulated series. According to the numerical results, consumption of the inattentive group is actually less volatile ($\sigma_{c^I} = 0.022$) and less correlated with income ($\rho_{c^I,y} = 0.846$) than consumption of the attentive group ($\sigma_{c^A} = 0.025$, $\rho_{c^A,y} = 0.982$). By accumulating

more wealth, an inattentive consumer improves her ability to smooth consumption fluctuations. This implies that, despite being fully rational and planning period by period, the attentive group bears the "costs" of living in an environment where half the population plans infrequently. Specifically, attentive consumers' consumption is more volatile as compared to what they would experience in a world with full attention. However, since their consumption profile is optimally chosen, they are also compensated for this utility cost by trading at more favorable prices. The net externality on the attentive consumers' welfare turns out to be positive. This will be further clarified in the next subsection, where I explicitly compute the welfare costs for both groups due to the presence of inattentiveness.

5.2 The costs of inattentiveness

To evaluate the welfare consequences of inattentiveness, I assume that agents start out with zero bond holdings and derive the level of expected lifetime utility by simulating 1,000 parallel series of 1,000 periods for the two groups of agents:

$$V^J = E_t \sum_{i=0}^{\infty} \beta^i \frac{(c_{t+i}^J)^{1-\mu}}{1-\mu}, \text{ for } J = A, I.$$

For the sake of comparison, I also derive the expected lifetime utility that would arise in a model without inattentiveness, where the representative agent consumes her income period by period:¹³

$$V^Y = E_t \sum_{i=0}^{\infty} \beta^i \frac{y_{t+i}^{1-\mu}}{1-\mu}.$$

Table 2.2 reports losses in terms of utility and translated into consumption units, namely the certainty equivalent level of consumption necessary to attain the same level of expected lifetime utility:

$$V^J = \frac{1}{1-\beta} \frac{(C^J)^{1-\mu}}{1-\mu} \text{ for } J = A, I, Y.$$

According to the results in Table 2.2, the welfare costs of inattentiveness are very small. The differences between the certainty equivalent consumption level of an

¹³ Variables with superscript Y refer to this last case.

attentive and an inattentive agent range from a minimum of 0.004% to a maximum of 0.07%, depending on the parameter configuration.¹⁴

The magnitude of these costs should not be very surprising. As a matter of fact, the results of this subsection can be seen as confirming previous findings that welfare gains from eliminating aggregate fluctuations are small (Lucas (1987)) and that losses due to small deviations from rationality are trivial (e.g. Cochrane (1989), Pischke (1995)). Idiosyncratic shocks, more uncertainty, higher income volatility or longer periods of inattentiveness, would probably magnify these costs. What is interesting is that attentive consumers are better off than in the representative agent case, as shown in the last row in Table 2.2. As noted in the previous subsection, in non-planning periods, only attentive consumers can react to aggregate income shocks which makes their consumption more volatile. However, they can trade at more favorable bond prices. In the basic case, the increase in consumption volatility is not sufficiently large to outweigh the favorable price effect. Conversely, inattentive agents are always worse off.

5.3 Some comparative statics

In this subsection, I simulate the inattentiveness model under different parameter configurations. In particular, I assess the impact of changes in risk aversion (μ), the persistence (ρ_y) or volatility (σ_y) of the income process, and the relative size of the inattentive group ($1 - \alpha$). The second column in Table 2.1 reports the parameter values I used in these comparative statics exercises and Table 2.2 summarizes my findings.

Increasing risk aversion, making income less persistent, or reducing the dimension of the attentive group, gives similar qualitative results (Table 2.2, columns 2, 3 and 4). In each of these cases, the inattentive group accumulates less bonds but pays

¹⁴ Losses in the same order of magnitude are obtained when welfare costs are computed as the time zero utility loss as a fraction of the present value of consumers' income stream, as described in Cochrane (1989):

$$pv = E_t \beta \sum_{i=0}^{\infty} \beta^i y_{t+i} = \bar{y} \frac{\beta}{1 - \beta},$$

and

$$\text{Time zero dollar loss} = L_{ij} = \frac{V_i - V_j}{u'(\bar{y}) pv} = \frac{\Delta V_{ij}}{\bar{y}^{1-\mu}} \frac{1 - \beta}{\beta}$$

where \bar{y} is normalized to one.

slightly higher and more volatile prices for its savings. This makes them reach a lower average level of consumption as compared to the benchmark case (Table 2.2, column 1). However, the mechanisms behind these results and the implications for the attentive group's consumption are different in the three cases.

A higher degree of risk aversion (column 2) leads inattentive consumers to accumulate less wealth. More risk aversion makes both agents more prudent and increase their precautionary saving motive. This requires larger movements in the bond prices to clear the market. Bond prices are more volatile and, on average, slightly higher which leads to a higher adverse price effect on inattentive consumers' savings. Thus, in the long run, higher risk aversion leads to lower wealth accumulation for inattentive agents, as shown by the stationary distribution in Table 2.2, and higher welfare losses due to inattentiveness. When risk aversion is higher, an inattentive agent's consumption is more correlated with income and, on average, lower. Conversely, the attentive group experiences a higher level of consumption and worse smoothing of income fluctuations compared to the benchmark case.

Similar results are obtained when income is less persistent (column 3). When $\rho_y = 0.5$, using savings as a buffer stock is less costly in terms of forgone consumption. Moreover, a less autocorrelated income process leaves more room for consumption smoothing. In this case, bond prices become three times more volatile than in the case when $\rho_y = 0.9$ and have a higher mean. As in the benchmark model, inattentive agents are lenders but now face more volatile and lower interest rates. In contrast to the case with higher risk aversion, they do better in terms of consumption smoothing. However, this is achieved through a lower level of consumption. Hence, being inattentive becomes more costly. On the other hand, the attentive group now experiences higher consumption volatility but, on average, attains higher consumption due to more favorable asset prices.

What happens if the inattentive group is larger (column 4)? In the comparative statics α is set to $\frac{1}{3}$, referring to Mankiw and Reis (2007) who find that inattentive consumers represent the majority.¹⁵ A larger fraction of the population being inattentive has a negative impact on their welfare. Even if the inattentive group is larger, an atomistic inattentive consumer does not internalize this effect. The

¹⁵ According to their estimation results, the fraction of people who receives new information every quarter is equal to 0.184. In their set-up, this implies that consumers will update their plans approximately every five quarters.

spillover effects on attentive agents are larger which makes their consumption more volatile. Since attentive consumers' consumption profile is optimally chosen, this requires larger movements in bond prices. As a result, prices are almost twice as volatile and, on average, higher than in the benchmark. This last effect makes attentive consumers still better off as compared to the full attention case ($C^A - C^Y > 0$). Even if their consumption profile is more volatile, they face more favorable prices on their assets.

Finally, a decrease in income volatility (last column) leads the inattentive group to accumulate less wealth for precautionary reasons and decreases the costs associated with being inattentive.

6 Inattentive savers

Infrequent planning also modifies the standard consumption/saving model in another important respect: what to plan becomes relevant. In other words, choosing consumption or saving is no longer equivalent. In the previous sections, I have been considering a model with inattentive consumers who let their savings absorb the income shock in non-planning periods. Consider now the maximization problem faced by an agent who chooses her *savings* every other period, while consumption fluctuates to satisfy the budget constraint:

$$\begin{aligned}
 V^I(z^P) &= \max_{b_{t+1}^I, b_{t+2}^I} \{U(y_t + b_t^I - q_t b_{t+1}^I) + \beta E_t V^I(z^{NP})\} \\
 st : \quad V^I(z^{NP}) &= U(y_t + b_t^I - q_t b_{t+1}^I) + \beta V^I(z^P) \\
 & \quad b_0^I = 0,
 \end{aligned} \tag{2.15}$$

where z^P and z^{NP} , represent the relevant set of state variables respectively in planning and non-planning periods, respectively. The problem in (2.15) can be rewritten in a more compact form:

$$\begin{aligned}
 V^I(s^P) &= \max_{b_{t+1}^I, b_{t+2}^I} \{U(y_t + b_t^I - q_t b_{t+1}^I) + \dots \\
 & \quad \beta E_t U(y_{t+1} + b_{t+1}^I - q_{t+1} b_{t+2}^I) + \beta^2 E_t V^I(s^P)\}.
 \end{aligned}$$

This yields the first-order conditions:

$$b_{t+1}^I : q_t (c_t^I)^{-\mu} = \beta E_t (c_t^I)^{-\mu}, \quad (2.16)$$

$$b_{t+2}^I : E_t q_{t+1} (c_t^I)^{-\mu} = \beta E_t (c_t^I)^{-\mu},$$

while for the attentive saver:

$$q_t (c_t^A)^{-\mu} = \beta E_t (c_{t+1}^A)^{-\mu} \quad (2.17)$$

$$q_{t+1} (c_{t+1}^A)^{-\mu} = \beta E_{t+1} (c_{t+2}^A)^{-\mu}.$$

In this case, it is possible to show that living hand-to-mouth, consuming y period by period, is an equilibrium. Moreover, this equilibrium is attained through a bond price equal to:

$$q_t = \beta y_t^\mu E_t (y_{t+1})^{-\mu}. \quad (2.18)$$

To see why zero saving at this bond price is an equilibrium is sufficient to note that it satisfies the attentive savers' Euler equations in (2.17):

$$q_t (y_t)^{-\mu} = \beta E_t (y_{t+1})^{-\mu}$$

$$q_{t+1} (y_{t+1})^{-\mu} = \beta E_{t+1} (y_{t+2})^{-\mu}.$$

By the law of iterated expectations, it follows that this bond price (eq.(2.18)) also satisfies the inattentive savers' Euler equations (eq. (2.16)):

$$q_t (y_t)^{-\mu} = \beta E_t (y_{t+1})^{-\mu}$$

$$E_t q_{t+1} (y_{t+1})^{-\mu} = \beta E_t (y_{t+2})^{-\mu}.$$

Since the optimality conditions are satisfied and market clearing conditions are trivially satisfied, we have $c_t^A = c_t^I = y_t$ as an equilibrium. This implies that a general equilibrium model where a fraction of the population infrequently plans its savings delivers the same equilibrium as a model with a representative agent with full information where bonds are in zero net supply. This result is driven by the assumptions that aggregate savings are zero, there are no idiosyncratic shocks and initial bond

holdings are zero so that agents are not heterogenous ex-ante. Under the same assumptions but with full attention, the representative agent would simply consume her income period by period. By fixing savings in advance, inattentive savers can reach the optimal full attention allocation even in an economy populated by infrequent planners, simply setting their savings equal to zero. Their consumption in this case will fluctuate to satisfy the budget constraint.

Suppose now that the inattentive group¹⁶ was given the collective choice of whether to infrequently plan consumption or savings. What would it optimally choose? Since the level of expected lifetime utility when making savings plans, V^Y , is higher than the value of being inattentive and making consumption plans V^I , (Table 2.2), an inattentive agent would choose to plan her savings and consume her income period by period.

In partial equilibrium and with endogenous planning frequency, Reis (2006) has shown that the choice of whether to be an inattentive saver or an inattentive consumer depends on the magnitude of the planning costs. He reached the conclusion that for planning costs above a certain threshold, consumers will rationally choose to make saving plans. In my general equilibrium model, abstracting from planning costs and with fixed planning frequency, the inattentive group is always better off if it plans its savings and this induces it not to accumulate wealth.

7 Inattentive investors

The results from the previous sections show that even in general equilibrium, higher uncertainty about future income induces inattentive consumers to accumulate more wealth. Thus, the empirical link between the propensity to plan and wealth accumulation mentioned in the introduction still appears to be a puzzle. However, if the source of uncertainty is asset returns rather than income, infrequent planning could lead to the opposite result, consistent with the empirical evidence. In this case more uncertainty may push the inattentive group towards less risky and less profitable portfolio choices. Several papers have explored the effects of infrequent planning on

¹⁶ It is important to stress that here, I am assuming that the group as a whole could take a collective choice. Considering the transfer of a single agent from inattentive savers to the inattentive consumers group would be a different exercise since in that case, prices would not be affected by the decision of an atomistic agent.

investment decisions in a partial equilibrium (e.g. Lynch (1996), Gabaix and Laibson (2002)) but little attention has been given to the problem in general equilibrium. In this section, I present a simple two-period model to elucidate the mechanisms behind investment decisions in a general equilibrium model with inattentiveness.

Consider the following model of portfolio decisions. There are two assets: b is a risk-free bond with price q , while s is a risky asset with dividend d and price, net of dividend, p . In each period, the dividend can only take two values: $d_H = 1 + \varepsilon$ or $d_L = 1 - \varepsilon$, each with probability $\frac{1}{2}$. The risk-free bond is in zero net supply, while the share is in unitary net supply.

As in the previously presented models, there are two groups of agents. Attentive investors choose their portfolio once the shock of period 1 is realized, the inattentive ones choose consumption and the risky asset s before the shock is realized. Utility is CRRA, $U = \frac{1-c^{1-\mu}}{1-\mu}$. Agents are homogenous ex ante ($b_0^J = 0$, $s_0^J = 1$ for $J = A, I$) and both groups are of equal size $\alpha = \frac{1}{2}$. The maximization problem faced by an attentive investor is therefore:

$$\begin{aligned} \max_{c_1^A, s_1^A} \quad & U(c_1^A) + \beta E_1 U(c_2^A) \\ \text{st} \quad & c_1^A + q_1 b_1^A + p_1 s_1^A = b_0^A + (p_1 + d_1) s_0^A \\ & c_2^A + q_2 b_2^A + p_2 s_2^A = b_1^A + (p_2 + d_2) s_1^A. \end{aligned} \quad (2.19)$$

The problem in (2.19) yields the following first-order conditions:

$$c_1^A : q_1 U'(c_1^A) = \beta E_1 U'(c_2^A)$$

$$s_1^A : p_1 U'(c_1^A) = \beta E_1 (d_2 + p_2) U'(c_2^A)$$

The maximization problem for an inattentive investor is:

$$\begin{aligned} \max_{c_1^I, s_1^I} \quad & U(c_1^I) + \beta E_0 U(c_2^I) \\ \text{st} \quad & c_1^I + q_1 b_1^I + p_1 s_1^I = b_0^I + (p_1 + d_1) s_0^I \\ & c_2^I + q_2 b_2^I + p_2 s_2^I = b_1^I + (p_2 + d_2) s_1^I, \end{aligned}$$

leading to the following optimality conditions:

$$c_1^I : q_1 U'(c_1^I) = \beta E_0 U'(c_2^I)$$

$$s_1^I : p_1 U'(c_1^I) = \beta E_0 (d_2 + p_2) U'(c_2^I)$$

The model is closed with the usual market clearing conditions:

$$\alpha b^A + (1 - \alpha) b^I = 0$$

$$\alpha s^A + (1 - \alpha) s^I = 1.$$

Unfortunately, even this simple version of the model cannot be solved analytically. Table 2.3 summarizes the numerical solutions for different sets of parameter values.¹⁷

As anticipated, facing higher uncertainty in asset returns, the inattentive group saves more in bonds and less in shares compared to the attentive group. The model generates highly volatile bond prices and high risk premia. Given the portfolio composition of inattentive investors, this makes the attentive investors accumulate ($E(w) = E(s + b)$) the most wealth.¹⁸ This effect on wealth accumulation is further magnified when the economy is more volatile (column 2).

This simple two-period model is thus capable of generating lower wealth of inattentive agents, in line with the empirical evidence. My results indicate that this effect is magnified when the risk premium is high, a case that seems to be empirically relevant. Future research should therefore be channeled in this direction.

8 Conclusions

This paper explores the links between the propensity to plan, wealth inequality, asset prices and welfare levels in general equilibrium. In a simple endowment economy where agents receive equal income streams, differences in the propensity to plan generate wealth heterogeneity and volatile asset prices. Attentive agents plan their consumption pattern period by period, while inattentive ones plan every other period. In a partial equilibrium model with fixed interest rates, Reis (2006) shows that inattentive consumers face more uncertainty and save more for precautionary reasons. Here, I show that in general equilibrium, inattentive consumers will accumulate more bonds when interest rates are low and reduce their bond holdings

¹⁷ In Table 2.3, H refers to a good dividend shock, while L stands for a bad shock.

¹⁸ Recall that $E(p_2 + d_2) = 1$ and that s_1^A is predetermined, since by the market clearing condition: $s_1^A = 1 - s_1^I$.

when interest rates are high. This negative term of trade effect might potentially lead to lower wealth. However, even in general equilibrium, inattentive consumers accumulate claims on attentive ones.

In my model, bond prices are much more volatile and much less autocorrelated than in a representative agent model with full attention. This is due to the fact that, in general equilibrium, prices must induce attentive agents to voluntarily bear the whole burden of adjusting to aggregate income shocks.

Moreover, I study the welfare consequences for both types of agents and find that the costs of being inattentive are modest and the attentive group is better off (once more, compared to a representative agent model with full attention).

Furthermore, I show that when the inattentive agents infrequently plan their savings rather than their consumption, they will not accumulate wealth and choose to live hand-to-mouth, consuming their income period by period. In this case, the equilibrium with inattentiveness mimics the equilibrium with full attention.

My results suggest that in order to replicate the empirical evidence in Ameriks, Caplin, and Leahy (2003) or Lusardi (2003), the standard consumption/saving model should be modified in other dimensions besides introducing heterogeneity in the propensity to plan. The propensity to plan might affect wealth along different channels. For example, infrequent planners might accumulate less wealth because they follow myopic (rule of thumbs) rules, because they have time inconsistent preferences or because they make different investment choices. The evidence in Lusardi (2003) hints that planning affects portfolio choices and that infrequent planners would choose less risky and profitable portfolios. Therefore, including a risky asset in my model might impoverish the inattentive agents. I indeed show that this can happen in a simple two-period model, for a reasonably high level of risk aversion. Interestingly, infrequent planning also endogenously induces inattentive investors to not participate to the stock market. Therefore, the model could potentially account for both the limited participation and the infrequency of active portfolio changes observed in the U.S. stock market.¹⁹ Future research should in-

¹⁹ Using data from the Surveys of Consumers Finances, Ameriks and Zeldes (2004) report that the in 2001, about half of the population does not hold any stocks and almost half of the sample members did not actively change their portfolio over a nine-year period. Polkovnichenko (2004) studies the implications of limited stock market participation on the equity premium in a theoretical model.

investigate the consequences of inattention in a more general infinite horizon portfolio choice model.

On the other hand, the results in Ameriks, Caplin, and Leahy (2003) and Venti and Wise (2000) suggest that differences in saving rather than financial choices are at the origin of wealth dispersion among households with the same characteristics. Present bias preferences, for example, could turn infrequent planners to overspenders.²⁰ Exploring these different channels is left to future research.

²⁰ In the behavioral literature, undersaving is often related to self-control problems (e.g. O'Donoghue and Rabin (1999), Ameriks, Caplin, and Leahy (2004)). O'Donoghue and Rabin (2007) point out that heterogeneity among agents with present bias might complicate incentive design.

Appendix

2.A Solution algorithm

The algorithm for the solution can be summarized as follows:

1. Define bond prices and consumption functions in the planning period as:

$$q^P = f_q^P(b^I, s^P), c^{I,P} = f_c(b^I, s^P)$$

2. Compute the state and consumption in the next period:

$$b_{t+1}^I = \frac{1}{q_t^P} (y_t - c_t^I + b_t^I) \Rightarrow$$

$$c_{t+1}^I = \left(\frac{q_t^P(\cdot)}{\beta} \right)^{-\frac{1}{\mu}} c_t^{I,P}(\cdot)$$

3. Define the price function in no-planning as $q_{t+1}^{NP} = f_q^{NP}(b^I, s^{NP})$

4. Compute the state and consumption in the next period:

$$b_{t+2}^I = \frac{1}{q_{t+1}^{NP}(\cdot)} (y_{t+1} - c_{t+1}^I + b_{t+1}^I) \Rightarrow$$

$$q_{t+2}^P = f_q^P(b^I, s^P), c_{t+2}^I = f_c(b^I, s^P)$$

These yield the following system of three equations

$$U' \left(\left(\frac{q_t^P(\cdot)}{\beta} \right)^{-\frac{1}{\mu}} c_t^I(\cdot) \right) = \beta^2 E_t \frac{1}{q_{t+1}^{NP}(\cdot)} U'(c_{t+2}^I(\cdot))$$

$$q_t^P(\cdot) U' \left(\frac{y_t - (1 - \alpha) c_t^I(\cdot)}{\alpha} \right) = \beta E_t U' \left(\frac{y_{t+1} - (1 - \alpha) \left(\frac{q_t^P(\cdot)}{\beta} \right)^{-\frac{1}{\mu}} c_t^I(\cdot)}{\alpha} \right)$$

$$q_{t+1}^{NP}(\cdot) U' \left(\frac{y_{t+1} - (1 - \alpha) c_{t+1}^I}{\alpha} \right) = \beta E_{t+1} U' \left(\frac{y_{t+2} - (1 - \alpha) c_{t+2}^I(\cdot)}{\alpha} \right)$$

where I made use of the market clearing conditions and the fact that consumption follows a deterministic path from t to $t + 1$

5. The solution to the model is given by a system of three functional equations in three unknowns, which I solved using Newton methods. The policy and price functions are approximated using linear splines.

2.B Borrowing constraint and penalty methods

In order to rule out equilibria which admit unbounded borrowing or Ponzi schemes, it is assumed in the numerical solution that there is a limit to the amount agents can go short on bonds represented by \underline{b} . Instead of dealing with inequality constraints, I modified the utility function introducing a penalty function to discourage the agents to borrow beyond the limit. Following Judd, Kubler, and Schmedder (2000), I used the following penalty function

$$K \min \{ (b_t^I - \underline{b}), 0 \}^\kappa, \text{ for } \kappa = \{2, 4\}$$

The modified maximization problem for an inattentive consumer is then

$$V^P(\cdot) = \text{Max}_{c_t^I, c_{t+1}^I} \left\{ \begin{array}{l} U(c_t^I) - K \min \{ (b_{t+1}^I - \underline{b}), 0 \}^\kappa + \beta U(c_{t+1}^I) - \dots \\ \beta K \min \{ (\min_{y_{t+1}} \{ b_{t+2}^I \} - \underline{b}), 0 \}^\kappa + \\ \beta^2 E_t V^P(\cdot) \end{array} \right\}$$

while for an attentive consumer

$$V^P(\cdot) = \text{Max}_{c_t^A} \{ U(c_t^A) - K \min \{ (b_{t+1}^A - \underline{b}), 0 \}^\kappa + \beta E_t V^{NP}(\cdot) \}$$

In equilibrium,

$$\begin{aligned} q_t(\cdot) [c_t^I(\cdot)]^{-\mu} &= \beta^2 E_t \frac{1}{q_{t+1}(\cdot)} [c_{t+2}^I(\cdot)]^{-\mu} - \phi_1 - \frac{1}{q_{t+1}(\cdot)} \phi_2 \\ q_t^P [c_t^I(\cdot)]^{-\mu} &= \beta [c_{t+1}^I]^{-\mu} - \phi_1, \\ q_t(\cdot) \left[\frac{y_t - (1-\alpha) c_t^I(\cdot)}{\alpha} \right]^{-\mu} &= \beta E_t \left[\frac{y_{t+1} - (1-\alpha) c_{t+1}^I}{\alpha} \right]^{-\mu} - \phi_3 \\ q_{t+1}(\cdot) \left[\frac{y_{t+1} - (1-\alpha) c_{t+1}^I}{\alpha} \right]^{-\mu} &= \beta E_{t+1} \left[\frac{y_{t+2} - (1-\alpha) c_{t+2}^I(\cdot)}{\alpha} \right]^{-\mu} - \phi_4 \end{aligned}$$

where

$$\phi_1 = K\kappa \min \{ (b_{t+1}^I - \underline{b}), 0 \}^{\kappa-1}$$

$$\phi_2 = \beta K\kappa \min \{ (\min b_{t+2}^I - \underline{b}), 0 \}^{\kappa-1}$$

$$\phi_3 = K\kappa \min \{ (b_{t+1}^A - \underline{b}), 0 \}^{\kappa-1}$$

$$\phi_4 = K\kappa \min \{ (b_{t+2}^A - \underline{b}), 0 \}^{\kappa-1}$$

2.C Tables and Figures

Table 2.1: Calibration

Variable	Description	Benchmark	Sensitivity Analysis
β	Discount factor	0.94	0.94
μ	Risk aversion	1.5	2
α	Dimension attentive group	$\frac{1}{2}$	$\frac{1}{3}$
κ	Penalty factor	4	4
\bar{y}	Mean of y	1	1
σ_y	Standard deviation. y	0.02	0.01
ρ_y	Autocorrelation	0.90	0.50
nY	Income states	3	3
nB	Grid points	111	111
\underline{b}	Debt limit	-2	-2

Table 2.2: Comparative Statics: Results

	$\mu = 1.5$ $\rho_y = 0.9$ $\sigma_y = 0.02$	$\mu = 2$ $\rho_y = 0.9$ $\sigma_y = 0.02$	$\mu = 1.5$ $\rho_y = 0.5$ $\sigma_y = 0.02$	$\mu = 1.5$ $\rho_y = 0.9$ $\alpha = \frac{1}{3}$	$\mu = 1.5$ $\rho_y = 0.9$ $\sigma_y = 0.01$
Simulation: sample moments					
$mean(c^I)$	1.018	1.015	1.017	1.013	1.018
$mean(c^A)$	0.982	0.985	0.983	0.973	0.982
$std(c^I)$	0.022	0.020	0.017	0.019	0.011
$std(c^A)$	0.025	0.024	0.030	0.027	0.012
$corr(c^I, y)$	0.846	0.906	0.719	0.934	0.860
$corr(c^A, y)$	0.883	0.935	0.917	0.871	0.897
$std(q)$	0.010	0.014	0.029	0.019	0.005
$mean(q)$	0.9402	0.9403	0.9411	0.9407	0.9401
$corr(\Delta b^I, q)$	0.804	0.549	0.446	0.443	0.862
Stationary distribution					
$Mean(b^I)$	0.304	0.239	0.287	0.221	0.302
$Var(b^I)$	0.019	0.011	0.017	0.005	0.023
Cost of inattentiveness					
$V^I - V^A$	-0.003	-0.003	-0.012	-0.006	-0.001
$V^I - V^Y$	-0.002	-0.002	-0.009	-0.003	-0.0002
$V^A - V^Y$	0.001	0.001	0.003	0.003	0.0004
$\left(\frac{C^I - C^A}{C^A}\right) \%$	-0.016	-0.020	-0.070	-0.036	-0.004
$\left(\frac{C^I - C^Y}{C^Y}\right) \%$	-0.012	-0.012	-0.051	-0.018	-0.001
$\left(\frac{C^A - C^Y}{C^Y}\right) \%$	0.004	0.008	0.019	0.018	0.002

Table 2.3: Inattentive investors in general equilibrium

	$\mu = 3$ $\varepsilon = 0.2$	$\mu = 3$ $\varepsilon = 0.3$
w_1^I	0.999	0.988
w_1^A	1.001	1.012
s_1^I	0.985	0.977
s_1^A	1.015	1.023
$E(b^I)$	0.014	0.011
$E(b^A)$	-0.014	-0.011
V^I	-1.268	-1.594
V^A	-1.059	-1.233
$\frac{1}{q_H}$	0.172	0.079
$\frac{1}{q_L}$	2.252	2.556
Equity premium	0.143	0.358
Equity premium (bad times)	0.263	0.694

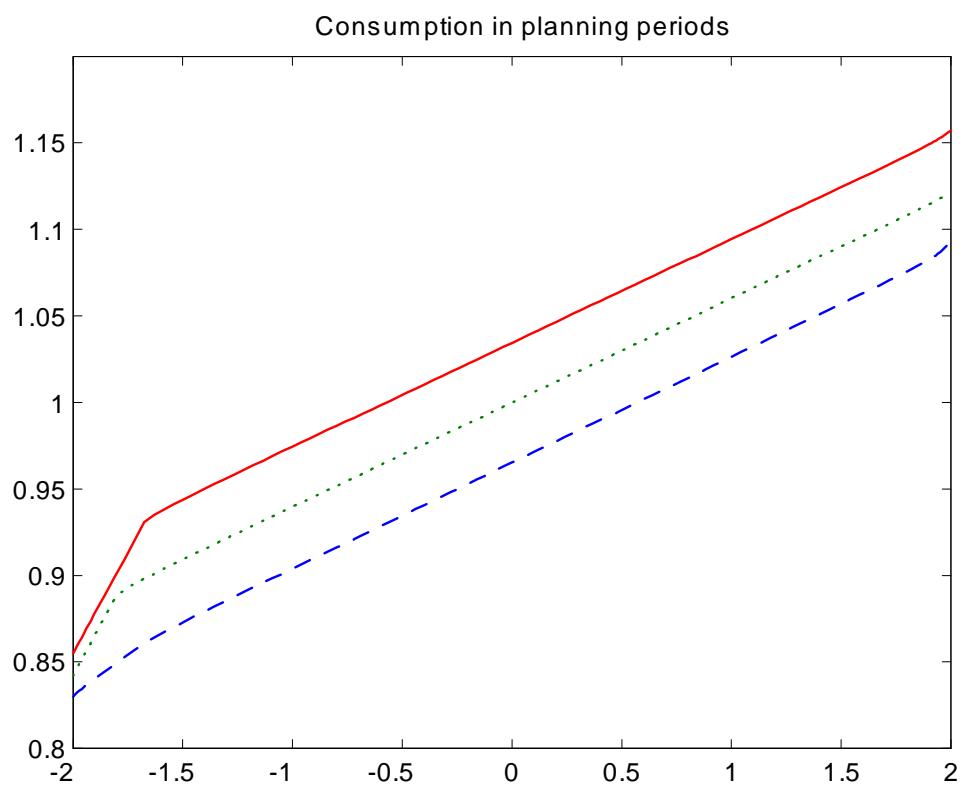


Figure 2.1: Consumption in planning periods plotted for the three realizations of the income shock: high (solid line), medium (dotted line) and low (dashed line)

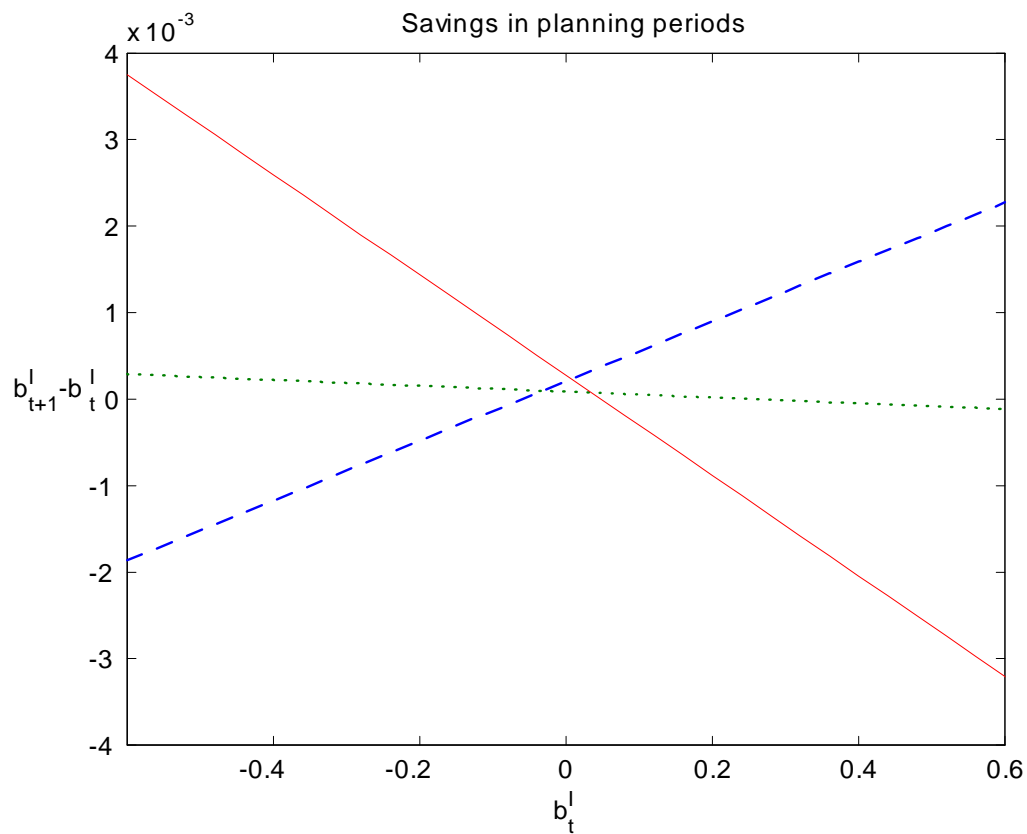


Figure 2.2: Inattentive consumers' savings behavior in planning periods as a function of initial bond holding and the three realizations of the income shock: high (solid line), medium (dotted line) and low (dashed line).

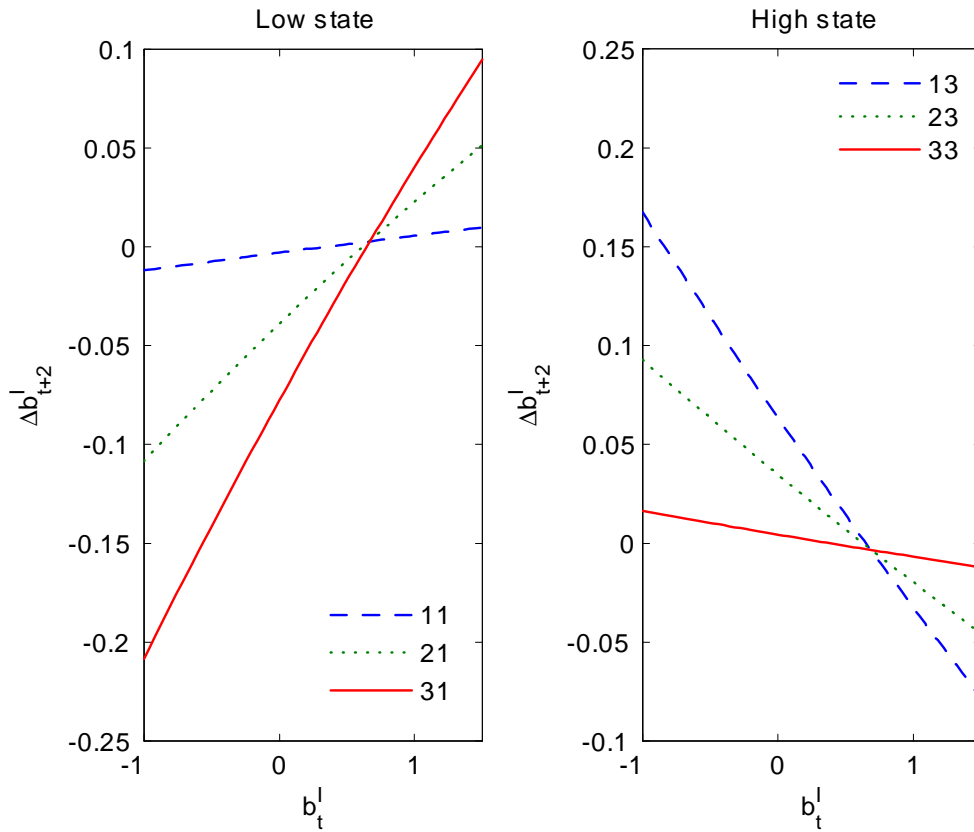


Figure 2.3: Savings in non-planning periods ($b_{t+2}^I - b_t^I$) for two realizations of the income shock in $t + 1$: low (left panel) and high (right panel). Each panel reports three different saving rules which depend on the initial income state in t . For example, in the left panel, 11 corresponds to $y_t = low \wedge y_{t+1} = low$, 21 corresponds to $y_t = medium \wedge y_{t+1} = low$ and 31 corresponds to $y_t = high \wedge y_{t+1} = low$

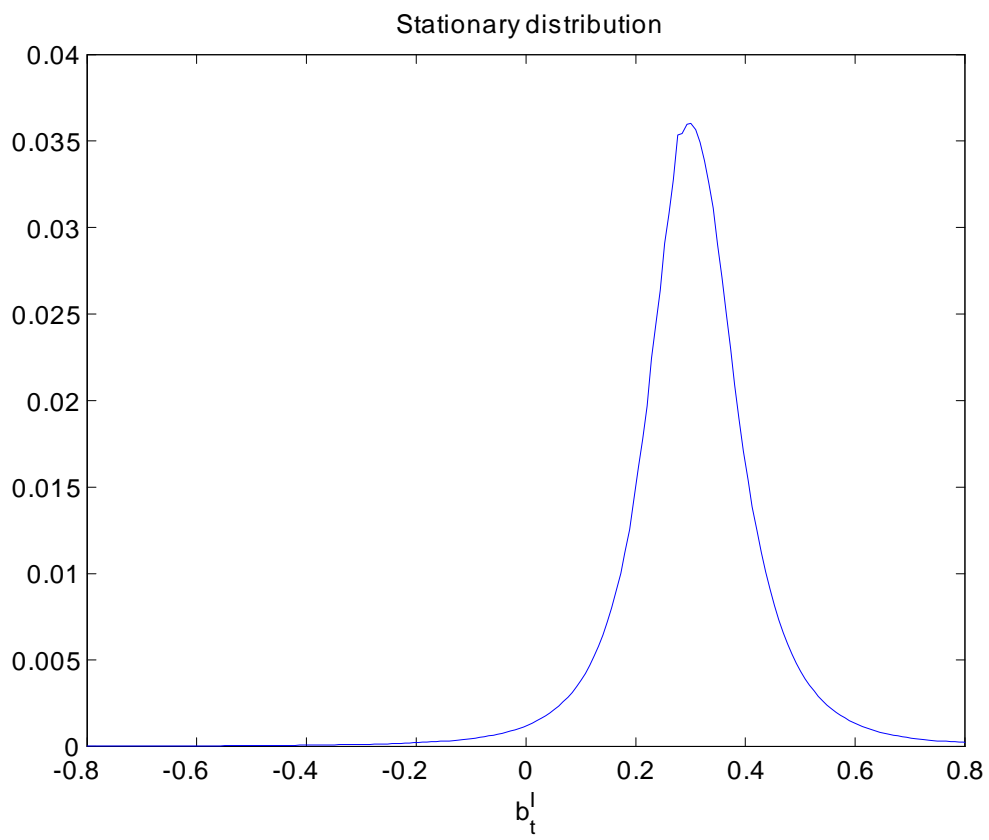


Figure 2.4: Long-run distribution of bond holdings of the inattentive group.

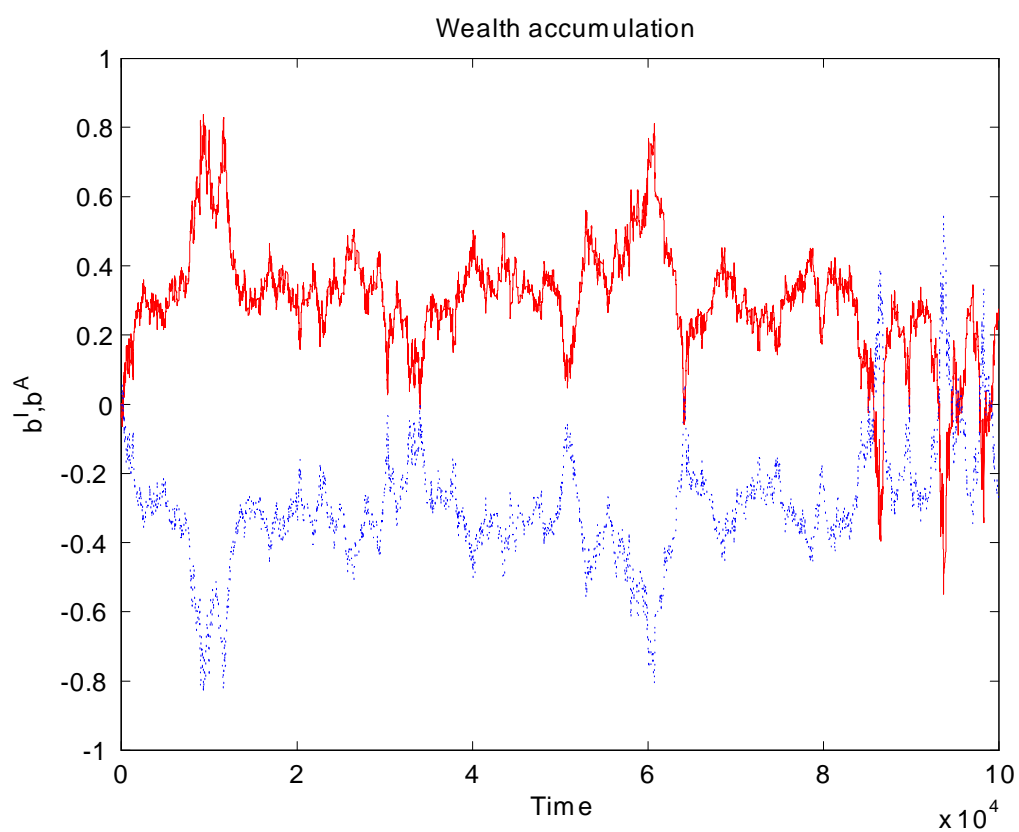


Figure 2.5: Simulated bond holdings for attentive (dotted line) and inattentive (solid line) consumers. Inattentive consumers accumulate more wealth

Chapter 3

Monetary Regime Change and Business Cycles^{*}

1 Introduction

After the breakdown of the Bretton Woods system several countries searched for new nominal anchors for their monetary policies. Many small open economies initially opted for some form of managed exchange rate regimes but, over time, most proved to be incapable of resisting the pressures of international capital markets. Given the proven inefficiency of such regimes, monetary authorities needed to find new anchors for the conduct of monetary policy. Inflation targeting soon became the new regime of choice, initially adopted by New Zealand and quickly followed by others, such as Canada, United Kingdom and Sweden. More than a decade after inflation targeting came into being, it is now time to evaluate to which extent such changes in monetary policy regime influence our view of economic dynamics.

In this paper, we look at Sweden as a good example of a small open economy that went through a monetary policy regime change. Sweden adopted an exchange rate target zone in 1977, setting a central parity for the Swedish krona against a basket of currencies and only allowing small deviations from that parity. After

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the dramatic and unsuccessful attempt at defending the currency at the end of 1992, Swedish authorities decided to abandon that exchange rate regime. Shortly thereafter, in January of 1993, the Riksbank (the central bank of Sweden) announced the adoption of an inflation targeting regime.¹

To analyze how the economic dynamics changed from one regime to the other, we estimate a small open economy dynamic stochastic general equilibrium (DSGE) model on Swedish data. Our main goal is to estimate the different monetary policy rules under the target zone and inflation targeting regimes, and analyze to what extent differences in monetary policy affected business cycle dynamics. In particular, having estimated the two different sets of interest rate responses, we compare the propagation of shocks in the two periods. Finally, we analyze to what extent the regime change implies a different decomposition of business cycle volatility.

The model in this paper, based on Kollmann (2001), incorporates physical capital, deviations from the law of one price (LOP) and Calvo price and wage setting. As shown by Betts and Devereux (2000), pricing-to-market (PTM) behavior by firms increases nominal and real exchange rate volatility. Considering the empirical failure of the LOP, Kollmann (2001) assumes that intermediate goods firms can price discriminate between domestic and foreign markets and that prices are set in the currency of their customers. To capture the well documented inertia in consumption, we include external habit formation in the utility function. Moreover, we assume frictions in financial markets to create a wedge between the returns on domestic and foreign assets. As in Benigno (2001), this "frictional" risk premium is assumed to be a decreasing function of the country's net foreign asset position.

We consider two different specifications for monetary policy. For the first part of the sample, the target zone period, we borrow part of the model in Svensson (1994). A linear managed float without an explicit band is used as an approximation to a non-linear exchange rate band model. In contrast to Svensson (1994), we describe monetary policy by an interest rate rule, whereby the monetary authority reacts to

¹ After the Bretton Woods collapse in 1973, Sweden participated in the so-called "snake" exchange rate mechanism. In 1977, the Riksbank announced a unilateral target zone to a currency basket constructed using trading weights. In May 1991, the ECU became the official target. Lindbeck, Molander, Persson, Petersson, Sandmo, Swedenborg, and Thygesen (1994), Lindberg, Söderlind, and Svensson (1993), Lindberg and Soderlind (1994) and the official web page of Sveriges Riksbank are good references for a more detailed description of the exchange rate regimes adopted in Sweden in the last century.

exchange rate deviations from the central parity. For the second part of the sample, we describe monetary policy with a Taylor-type rule where the central bank reacts to current inflation, output and, potentially, exchange rate movements.

Eight structural shocks complete the model specification: shocks to preferences, labor supply, productivity, monetary policy, risk premium, wage and price markups and realignment expectations.² In addition, three more shocks enter a pre-estimated VAR representing the foreign sector. This way, ten macroeconomic time series enter the estimation: foreign interest rate, foreign inflation, foreign output, domestic output, domestic inflation, domestic interest rate, nominal exchange rate, real wages, hours worked and private consumption. Following Smets and Wouters (2003), we estimate the model using Bayesian methods. To investigate the business cycle and the propagation of the eleven shocks under the two regimes, we compute variance decompositions and impulse response functions.

The policy rule we estimate suggests that, during the target zone period, the Riksbank primarily reacted to exchange rate deviations from the central parity, without ignoring inflation and output, however. As emphasized in Svensson (1994), the main advantage of a target zone, as compared to a fixed peg, is that it gives the monetary authority the ability to stabilize the exchange rate without losing all its flexibility to react to domestic shocks. Our results confirm this view. Still, foreign shocks hit the economy harder, because the exchange rate cannot act as a shock absorber. This shows up in the impulse response analysis, where foreign shocks in general have a stronger impact on domestic variables in the target zone period than in the inflation targeting one. Under inflation targeting, the central bank instead reacted primarily to inflation, thereby generating a stronger response to domestic shocks. Shocks to foreign variables were mostly absorbed by the exchange rate, leaving only a small impact on domestic variables.

According to the variance decomposition analysis, realignment expectations shocks were the main source of economic volatility during the target zone. The volatility of

² In a target zone, the exchange rate is allowed to float around the central parity within tight bands. If the pressures on the exchange rate are too strong, the authorities might decide to change the central parity. Therefore, investors form expectations about these changes, and this is what we here describe as realignment expectations. Usually the pressure is more on the devaluation side and hence, we shall use the terms "realignment expectations" and "devaluation expectations" interchangeably. As will be further discussed in the model description, we assume these expectations to be subject to shocks. These shocks, obviously, only play a role in the target zone period.

the real exchange rate is mostly explained by risk premium and realignment expectations shocks in the short run in both regimes. But, in the long run, labor supply shocks drive most of the volatility in the real exchange rate. Shocks to foreign variables are not a significant source of volatility in the economy. However, the impulse response analysis shows that the foreign sector still plays a relevant role in the transmission mechanism of the model. Furthermore, realignment expectations shocks (in the target zone) and risk premium shocks (in both periods) do play an important role in explaining the volatility and these shocks very likely originate abroad.

The main conclusion of this paper is then that the influence of different shocks is very different in the two regimes and therefore, it is important to account for the regime change in the estimated DSGE to capture properly the information in the data. If the model is estimated in the entire sample without accounting for it, then we risk capturing business cycle properties that are averaged across the two periods.

Structural estimation of small open economy models has been subject to extensive research in the recent past. Ghironi (2000) uses non-linear least squares and full maximum likelihood (ML) to estimate a two-country model with overlapping generations on Canadian and US data. Smets and Wouters (2002) and Lindé, Nessén, and Söderström (2004) estimate their models, on Euro and Swedish data respectively, minimizing the distance between empirical and model based impulse responses. Dib (2003), Ambler, Dib, and Rebei (2003) and Bergin (2003) use ML procedures to estimate small open economy models with nominal rigidities and different kinds of structural shocks.

The problem with such approaches is that the models involve a large number of coefficients and highly non-linear likelihoods. Smets and Wouters (2003) show the advantages of using Bayesian techniques to estimate a DSGE closed economy model on Euro data. Adolfson, Laséen, Lindé, and Villani (2007a) extend that work, applying the same approach on an open economy model for the Euro area. Other recent papers that estimate open economy models with Bayesian methods include Justiniano and Preston (2006b,a) and Lubik and Schorfheide (2007).

In contrast to the previous literature, this paper consider the effects of monetary regime change on the dynamics of a small open economy. In this way, the paper contributes to the literature on time varying DSGE models, e.g., Fernández-Villaverde and Rubio-Ramírez (2007) and Justiniano and Primiceri (2007). However, in con-

trast to those papers, we model a specific change of monetary policy regimes, rather than allowing specific parameters to change over time.

Independent work by Adolfson, Laséen, Lindé, and Villani (2007b) also considers the change in monetary policy due to the adoption of inflation targeting in Sweden. However, the regime change is not the main focus of their paper which only considers the impact of regime change on the stability of the interest rate rule parameters. Instead, we focus on the overall monetary policy regime, and evaluate the role of devaluation expectations during the target zone, which turn out to be essential for the volatility of that period.

The rest of the paper is organized as follows. Section 2 presents the theoretical model. Section 3 briefly describes the data set, the estimation procedure, and our priors. In Section 4, we present the results in terms of parameter estimates, impulse response functions and variance decomposition. Section 5 concludes.

2 The Model

The model closely follows Kollmann (2001) who considers a small open economy with a representative household, firms and a government. A single nontradable final good is produced by the domestic country, as well as a continuum of intermediate tradable goods. The final good market is perfectly competitive, while there is monopolistic competition in the intermediate goods market. Prices are assumed to be sticky in the buyer's currency. This assumption, commonly denominated as local currency pricing (LCP), is supported by empirical evidence on Swedish exporters' invoicing practice,³ and influences the role of the exchange rate in the international transmission mechanism. Specifically, local currency pricing shuts down the expenditure switching effect of the exchange rate, in the domestic country. Instead, exchange rate depreciations (appreciation) have a wealth effect on exporters' profits raising (decreasing) their markups. Thus, in the model, a nominal depreciation improves the domestic country's terms of trade.

The household owns the domestic firms, holds one-period domestic and foreign currency bonds and rents capital to firms. Overlapping wage contracts à la Calvo are assumed. Here, we modify the original model by introducing habit persistence

³ See Wilander (2006) and Friberg and Wilander (2007).

in consumption, assuming the monetary authority to follow a Taylor rule, explicitly modelling the target zone period and enriching the dynamics of the model with eight structural shocks. Moreover, following Benigno (2001), we model the risk premium on the return to foreign borrowing as a function of the level of net foreign assets. In the next subsections, we describe each sector of the economy in more detail. For ease of presentation in the text we only set up the agents' optimization problems leaving the full and final list of equations (already log-linearized) to Appendix 3.A.

2.1 Final goods production

A non-tradable final good is produced in a perfectly competitive market using domestically produced (Q^d) and imported (Q^m) intermediate goods according to the following technology:

$$Z_t = \left(\frac{Q_t^d}{\alpha^d} \right)^{\alpha^d} \left(\frac{Q_t^m}{1 - \alpha^d} \right)^{1 - \alpha^d},$$

where

$$Q_t^i = \left[\int_0^1 q_t^i(s)^{\frac{1}{1+\nu_t}} ds \right]^{1+\nu_t}, \quad i = d, m$$

are the domestic and the imported intermediate input quantity indices, $q_t^d(s)$ and $q_t^m(s)$ the domestic and imported type "s" intermediate goods and ν_t time varying price markup shock.

Cost minimization implies demand for inputs:

$$q_t^i(s) = Q_t^i \left(\frac{p_t^i(s)}{P_t^i} \right)^{-\frac{1+\nu_t}{\nu_t}}, \quad i = d, m$$

$$Q_t^i = \alpha^i \frac{P_t Z_t}{P_t^i},$$

and price indices:

$$P_t^i = \left[\int_0^1 p_t^i(s)^{-\frac{1}{\nu_t}} ds \right]^{-\nu_t},$$

$$P_t = (P_t^d)^{\alpha^d} (P_t^m)^{1 - \alpha^d}.$$

2.2 Intermediate goods production

In the intermediate goods market, a range of monopolistically competitive firms combine labor (L) and capital (K) according to the following technology:

$$y_t(s) = \theta_t K_t(s)^\psi L_t(s)^{1-\psi},$$

with

$$L_t(s) = \left[\int_0^1 l_t(h; s)^{\frac{1}{1+\gamma_t}} dh \right]^{1+\gamma_t},$$

where γ_t is a time varying wage markup.

Cost minimization implies

$$W_t = \left[\int_0^1 w_t(h)^{-\frac{1}{\gamma_t}} dh \right]^{-\gamma_t},$$

where $w_t(h)$ denotes the nominal wage of worker h and W_t is the price index for labor inputs. The firm's production is sold at both domestic and foreign markets:

$$y_t(s) = q_t^d(s) + q_t^x(s).$$

Export demand is assumed to be similar to domestic demand function in that total foreign demand are allocated to the different varieties according to the same elasticity:

$$Q_t^x = \left[\int_0^1 q_t^x(s)^{\frac{1}{1+\nu_t}} ds \right]^{1+\nu_t}.$$

Foreign demand is given by

$$Q_t^x = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta} Y_t^*,$$

where Y_t^* is foreign real GDP and P_t^* the foreign aggregate price level. The demand for each variety is therefore similar to domestic demand:

$$q_t^x(s) = Q_t^x \left(\frac{p_t^x(s)}{P_t^x} \right)^{-\frac{1+\nu_t}{\nu_t}},$$

with price index:

$$P_t^x = \left[\int_0^1 p_t^x(s)^{-\frac{1}{\nu_t}} ds \right]^{-\nu_t}.$$

The profits from producing and importing are

$$\Pi_{t+\tau}^i(p_t^i) = (P_{t+\tau}^i)^{\frac{1+\nu_{t+\tau}}{\nu_{t+\tau}}} Q_{t+\tau}^i \left[(p_t^i)^{-\frac{1}{\nu_{t+\tau}}} - S_{t+\tau}^i (p_t^i)^{-\frac{1+\nu_{t+\tau}}{\nu_{t+\tau}}} \right], \text{ for } i = d, m, x,$$

where S_t^i is the marginal cost. Firms can price discriminate among the domestic and foreign markets and set prices in the currency of the buyer. The firms' profit maximization problem is therefore:

$$\begin{aligned} \max_{p_t^i} \quad & \sum_{\tau=0}^{\infty} \alpha_p^\tau E_t [\rho_{t,t+\tau} \Pi_{t+\tau}^i(p_t^i)] \\ \text{s.t.} \quad & \Pi_{t+\tau}^i(p_t^i) = (P_{t+\tau}^i)^{\frac{1+\nu_{t+\tau}}{\nu_{t+\tau}}} Q_{t+\tau}^i \left[(p_t^i)^{-\frac{1}{\nu_{t+\tau}}} - S_{t+\tau}^i (p_t^i)^{-\frac{1+\nu_{t+\tau}}{\nu_{t+\tau}}} \right], \end{aligned}$$

where

$$\rho_{t,t+\tau} = \beta^\tau \frac{\xi_{t+\tau} U_c(t+\tau)}{\xi_t U_c(t)} \frac{P_t}{P_{t+\tau}},$$

is the discount factor in domestic currency and $(1 - \alpha_p)$ is the probability of being able to set the price in a given period.

2.3 The representative household

The representative household (HH) maximizes expected utility:⁴

$$\max E_0 \sum_{t=1}^{\infty} \beta^t \xi_t \left[\frac{1}{1 - \sigma_c} (C_t - v \tilde{C}_{t-1})^{1 - \sigma_c} - \kappa_t \int_0^1 \frac{l_t(h)^{1 + \sigma_l}}{1 + \sigma_l} dh \right]$$

where $l_t(h)$ represents the quantity of labor of type h supplied and \tilde{C}_{t-1} past aggregate consumption, taken as exogenous by each individual household. As in Smets and Wouters (2003), we introduce two preference shocks in the utility function: ξ_t , which affects the intertemporal elasticity of substitution and κ_t , a shock to the disutility of labor relative to the utility of consumption.

The household invests in capital:

$$K_{t+1} = (1 - \delta) K_t + I_t - \phi(K_{t+1}, K_t),$$

where the convex adjustment costs are given by $\phi(K_{t+1}, K_t) = \frac{\Phi}{2} \frac{(K_{t+1} - K_t)^2}{K_t}$.

⁴ Here, we assume a cashless limiting economy as in Woodford (2003).

Frictions in financial markets create a wedge between the returns to domestic and foreign assets. As in Benigno (2001), this risk premium is assumed to be a decreasing function of the country's net foreign asset position:

$$\Omega_t = \exp \left\{ -\frac{\omega}{2\Upsilon} \frac{e_t B_t}{P_t} + \zeta_t \right\},$$

where ζ_t is an exogenous shock and Υ is the steady state value of exports in units of domestic final goods ($\Upsilon = \frac{eP^x Q^x}{P}$). This implies that households pay an increasing intermediation premium on their debt.⁵

The budget constraint is:

$$\begin{aligned} A_t + e_t B_t + P_t (C_t + I_t) &= (1 + i_{t-1}) A_{t-1} \\ &+ (1 + i_{t-1}^*) \Omega_{t-1} e_t B_{t-1} + R_t K_t \\ &+ \sum_{i=d,x,m} \int_0^1 \Pi_t^i(s) ds + \int_0^1 \int_0^1 w_t(h) l_t(h; s) dh ds, \end{aligned}$$

where A_t and B_t are stocks of domestic and foreign assets at the end of period t . With probability $(1 - \alpha_w)$, the household is able to set the wage for type h labor, taking the average wage rate W_t as given and satisfying the demand for labor of each type:

$$l_t(h) = \chi_t w_t(h)^{-\frac{1+\gamma_t}{\gamma_t}},$$

where $\chi_t = \psi^{-1} (1 - \psi) (W_t)^{\frac{1}{\gamma_t}} R_t K_t$.

2.4 Monetary authority

The model accounts for the monetary policy regime shift in Sweden after the 1992 crisis. The data set considered in this paper begins in 1980. Monetary policy between that year and the third quarter of 1992 is best described as a target zone regime. During this first part of the sample, we follow Svensson (1994) by explicitly modeling expectations of realignment and deviations from central parity. However, we depart from that paper by introducing an interest rate rule taking into account exchange rate deviations instead of deriving the optimal policy behavior.

⁵ The financial frictions generate a wedge between borrowing and lending to foreigners. This, together with the assumption that $\beta(1 + i^*) = 1$, leads to an optimal choice of zero net foreign assets in a non-stochastic steady state.

After the exchange rate crisis in 1992, the Riksbank decided to let the krona float and enter a regime of explicit inflation targeting. In the floating regime, monetary policy is represented by a simple Taylor type rule with the interest rate responsive to inflation, output, exchange rate movements and interest rate smoothing.

2.4.1 Target zone

Following Svensson (1994), we write the exchange rate as $\hat{e}_t = \hat{e}_{c,t} + \hat{e}_{x,t}$, where $\hat{e}_{c,t}$ is the central parity exchange rate and $\hat{e}_{x,t}$ refers to the deviations of the exchange rate from central parity. It follows that expected realignments satisfy:

$$E_t [\hat{e}_{t+1} - \hat{e}_t] = E_t [\hat{e}_{c,t+1} - \hat{e}_{c,t}] + E_t [\hat{e}_{x,t+1} - \hat{e}_{x,t}]. \quad (3.1)$$

Realignment expectations have an endogenous component, here modeled as a linear response to the exchange rate deviations from central parity, and an exogenous component which follows an AR(1) process:⁶

$$\begin{aligned} E_t [\hat{e}_{c,t+1} - \hat{e}_{c,t}] &= g_t + \rho_x \hat{e}_{x,t} \\ g_t &= \rho_g g_{t-1} + \varepsilon_{g,t}. \end{aligned} \quad (3.2)$$

Compared to a fully fixed exchange rate system, a target zone regime gives central banks more flexibility in the management of the exchange rate, thereby allowing monetary policy to be used for other purposes. Nevertheless, the central bank is constrained to use the policy instrument to also keep the exchange rate close to central parity and fight expectations of realignment. Therefore, we represent monetary policy by a modified Taylor rule taking into account the reaction to exchange rate deviations from the central parity:

$$\hat{i}_t = \rho_{m,TZ} \hat{i}_{t-1} + (1 - \rho_{m,TZ}) \left[\Gamma_{p,TZ} \hat{\pi}_t + \Gamma_{y,TZ} \hat{Y}_t / 4 + \Gamma_{x,TZ} \hat{e}_{x,t} \right] + \varepsilon_{m,TZ,t},$$

where $\hat{\pi}_t$ and \hat{Y}_t are expressed as percentage deviations from steady state values, $\varepsilon_{m,t}$ is an i.i.d. shock which captures the non systematic component of monetary policy, \bar{i}_t is the target for the interest rate and \hat{i}_t is defined by $\hat{i}_t \equiv \frac{i_t - \bar{i}}{1 + \bar{i}}$. Inserting

⁶ This shock is identified relative to the risk premium shock as it plays a role only during the target zone period.

(3.2) into (3.1), we get an expression for the expectations of depreciation:

$$E_t [\hat{e}_{t+1} - \hat{e}_t] = E_t \hat{e}_{x,t+1} + g_t - (1 - \rho_x) \hat{e}_{x,t};$$

an expression which will appear in the uncovered interest rate parity relation for the target zone period.

2.4.2 Free Floating with Inflation Targeting

In the free floating period, the monetary authority is no longer constrained in its role of steering the economy. It is reasonable to expect that it might want to achieve greater interest rate smoothing, more aggressiveness in its the reaction to inflation and more responsiveness to output fluctuations. This will be part of the empirical question we are trying to address, namely to what extent the target zone limits central bank reactions to inflation and output changes as well as the degree of interest rate smoothing. Moreover, according to the results in Lubik and Schorfheide (2007), the Bank of Canada and the Bank of England include the nominal exchange rate in their policy rules. Hence, we model monetary policy through a standard log-linearized Taylor rule augmented with a reaction to exchange rate movements:

$$\hat{i}_t = \rho_{m,FF} \hat{i}_{t-1} + (1 - \rho_{m,FF}) \left[\Gamma_{p,FF} \hat{\pi}_t + \Gamma_{y,FF} \hat{Y}_t / 4 + \Gamma_{x,FF} \Delta \hat{e}_t \right] + \varepsilon_{m,FF,t}.$$

Note that the two interest rate rules have coefficients that depend on the regime, precisely to allow for different coefficients on output, inflation, nominal exchange rate and interest rate in the two regimes. Moreover, the variance of the monetary policy shock is allowed to vary across the two subsamples.

2.5 Foreign Sector

For simplicity, we treat the foreign sector as exogenous and assume that foreign output, inflation and interest rate follow a linear VAR model with one lag:

$$G_0 \begin{bmatrix} \hat{Y}_t^* \\ \hat{\pi}_t^* \\ \hat{i}_t^* \end{bmatrix} = G_1 \begin{bmatrix} \hat{Y}_{t-1}^* \\ \hat{\pi}_{t-1}^* \\ \hat{i}_{t-1}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_y^* \\ \varepsilon_p^* \\ \varepsilon_i^* \end{bmatrix}.$$

We pre-estimate the foreign VAR using standard OLS methods and keep these

parameters fixed through the estimation of the DSGE model.

2.6 Equilibrium

The equilibrium in the domestic goods market requires that:

$$Z_t = C_t + I_t,$$

$$K_t = \int_0^1 K_t(s) ds.$$

It is assumed that no foreigners hold domestic assets, so that in equilibrium:

$$A_t = 0.$$

Finally, in equilibrium, it is possible to recover the Balance of Payments equation from the budget constraint:

$$B_t = (1 + i_{t-1}^*) \Omega_{t-1} B_{t-1} + P_t^x Q_t^x - P_t^* Q_t^m.$$

2.7 Shock structure

There are eight structural shocks in the economy: to preferences, productivity, risk premium, labor supply, realignment expectations, Taylor rule, price markup and wage markup. The first five follow stochastic processes given by:

$$z_t = (1 - \rho_z) + \rho_z z_{t-1} + \varepsilon_{z,t},$$

while that the two markup shocks and the monetary shock are iid and take the form:

$$z_t = z + (1 + z) \varepsilon_{z,t}.$$

The shock structure is completed by three additional shocks, to foreign inflation, output and interest rate, included in the pre-estimated exogenous foreign VAR.

The model is solved and estimated in loglinear form around its deterministic steady state.⁷

⁷ We solve the model using the Matlab routine *gensys.m*, created by Christopher Sims. The

3 Estimation

Following Smets and Wouters (2003), we estimate the model using Bayesian techniques, but we explicitly incorporate the regime change and analyze to which extent it influences the estimated results. To construct the likelihood of the model, we write the system in state space form for each period/regime, and match the observables with latent variables through a system of observation equations.^{8,9} After forming the posterior density, we estimate its mode through numerical optimization methods. Then, we generate a sample of draws representative for the posterior using Markov Chain Monte Carlo (MCMC) methods.

The next three subsections describe our data, our priors, and our MCMC methodology.

3.1 Data

Our data set contains quarterly data over the period 1980:1 - 2002:3. The data refers to Sweden and a foreign sector which is a composite of eight foreign countries among its major trading partners: Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, United Kingdom, and United States.¹⁰ We limit the set of observables to the following ten series: foreign interest rate, foreign consumer price index (CPI), foreign output, domestic output, domestic CPI, domestic interest rate, nominal exchange rate, real wages, hours worked and consumption.

To construct foreign variables, we aggregate national variables according to their trade weights. In the nominal variables (CPI, interest rate and exchange rate), the

log-linearized equilibrium conditions are presented in Appendix 3.A.

⁸ Because the steady state is exactly the same in both periods, the variables in log-deviations from steady state convey exactly the same interpretation in both regimes, as they are referring to the same steady state.

⁹ More precisely, we proceed as follows. First, we set the state space form for the target zone period initializing the Kalman filter with mean zero and an identity covariance matrix. Then, we eliminate the last observation of the target zone subsample and the first of free floating/inflation targeting to minimize the effects of breaks in expectations in the theoretical model. We restart the Kalman filter for the second subsample with a mean equal to the values of the state variables of the last observation available for the target zone. The covariance matrix is set equal to the covariance matrix in the last period of the first subsample for the state variables that are common in both regimes, but multiplied by a factor of $(1.5)^2$ to imply that there is some increase in uncertainty about the filter. For the iteration of the Kalman filter, we used the *kf.m* Matlab routine, created by Christopher Sims.

¹⁰ Appendix 3.B presents a more detailed description of the data set, including the data sources.

US has double weight, in accordance with the actual basket which the Riksbank targeted in the first half of our sample.¹¹ Given that we have a general equilibrium model, we also use a double weight for prices and interest rates, but not for real output (the driving force behind the real demand for exports). We maintain the same weighting scheme through the second part of the sample to keep the model consistent.

All data series are logged and detrended by a linear trend. An exception is the interest rates, for which the gaps were defined as in the text, i.e., as the difference between the level and the trend divided by the gross interest rate value of the trend. The detrending process aims at making the theoretical model consistent with the data: in the theoretical model, we have deviations from steady state and thus, we should remove the major shifts in the data, which are more likely associated with steady state changes (not explicitly modeled here). We start with the exchange rate process, i.e., the least standard one.

For the exchange rate, we must take into account that there are two regimes and the trend is therefore different. During a *credible* target zone, the trend should simply be a constant, except for revaluations and devaluations. In the case of the Swedish krona, Figure 3.1 reveals two devaluations, one in September 1981 and another in October 1982. After these devaluations and until 1992, the exchange rate was more or less constant and there was no clear trend of departure from central parity. We take central parity as the trend for this period. Therefore, we treat the deviations from central parity as an observable. The reason for this treatment of the exchange rate in the target zone period is that we do not want to explicitly model the determinants of devaluations, so we consider the central parity variable to always be constant, despite the two devaluations actually observed. This is a simplification which could be reconsidered in subsequent research. In the second quarter of 1991, central parity switched to be in terms of the ECU composite currency instead of the previous basket. This regime only lasted until the end of 1992. Since this is such a short time period and still a target zone regime, we simplify by assuming that the previous regime was still in place. This is another a simplification, but once more we consider this to be one first step in the analysis of the Swedish case. Therefore,

¹¹ The reason behind this, as explained in Franzen, Markowski, and Rosenberg (1980), is that most raw materials used to be priced in US dollars.

we consider the target zone subsample to go through 1980:1 to 1992:4. For the free floating period, we compute a simple linear trend.

We computed a linear trend for the inflation rate in Sweden and the foreign inflation aggregate. For the price level, we used the inflation trend to accumulate recursively to the original price level in each period. For the interest rates, we subtracted the linear inflation trend and then subtracted the mean of the difference, which can be understood as the average real interest rate.

3.2 Priors

In Bayesian estimation, priors fulfill two important purposes. The first is to incorporate information about some of the parameters of interest to narrow down the possible scope of search, thereby allowing for more precise estimation. In this sense, we are making a strict Bayesian updating on previously available information. The modes can then be considered as reflecting previous calibrated or estimated values and the variances as reflecting our confidence in them. The second purpose of priors is to smooth the search and move it away from theoretically unacceptable parameter values that do not make any sense (like restricting the parameters to be positive). In setting the priors, we take these two purposes into account. The main properties of our prior distributions are presented in Table 3.1.

Technology, utility and price setting parameters are assumed to be Normal, Beta (whenever the parameter should vary in a range between zero and one), or Gamma (whenever parameters should be positive). Lindé (2004) calibrates the price elasticity of aggregate exports (η) for Sweden at 1, referring to the findings of Johansson (1998) who estimates this parameter at 1.3 for manufactured goods and at 0.7 for the services sectors. We use a prior distributed as an inverted gamma with the mean at 1.5 and a standard error of 0.3. Apel, Friberg, and Hallsten (2005) provide a survey of Swedish firms according to which firms change their prices once a year. However, using macro data, both Smets and Wouters (2003) and Adolfson, Laséen, Lindé, and Villani (2007a) estimate a higher degree of price rigidity for the Euro area. Therefore, for both Calvo parameters α_p and α_w , we choose a beta distribution with the mode 0.8 and a standard error of 0.1. The prior for the risk aversion parameter is a Normal with mean 2, consistent with the calibrated value used by Kollmann (2001) and the value estimated by Lindé, Nessén, and Söderström (2004). In Smets and

Wouters (2003), the prior for the habit persistence parameter (ν) is distributed as a beta with the mean 0.70, while Adolfson, Laséen, Lindé, and Villani (2007a) have a prior with a lower mean, 0.65. We choose a beta with a mean of 0.7 and a standard error of 0.1. As concerns the other utility parameter, the inverse elasticity of labor supply (σ_l), we chose a normal with mean 1. For the adjustments cost parameter Φ , we use a gamma with a mean of 10 and a standard error of 5 to encompass the values used in Kollmann (2001). Lane and Milesi-Ferretti (2001) regress the interest rate differential on NFA/exports and estimate the financial frictions at 2.8. In our model, this would correspond to a ω of 0.0035, so this was used as the mode for our prior.

We consider identical priors for the monetary policy rule parameters for both the target zone and the free floating periods. More precisely, we assume Γ_p and Γ_y to be distributed according to gammas with means of 2 and 0.6. The prior for the interest rate smoothing parameter (ρ_m) is distributed as a beta with a mean of 0.8, while the Taylor rule parameter on the exchange rate (Γ_x) is a gamma with a mean of 3 and a standard error of 2. These parameters for Γ_x are to some extent based on the theoretical experiments and the empirical analysis by Svensson (1994). The mode for the coefficient for the endogenous part in the realignment expectations (ρ_x) is set at 0.35, based on Svensson's estimates of 1.4 for yearly data (but referred to as an upper limit).

All variances in the structural shocks are assumed to be distributed as inverted Gammas. Finally, we assume the autocorrelation coefficients of the shocks to follow a beta with a mean of 0.8 and a standard error of 0.1.

We choose to calibrate some parameters that are related to steady state levels and therefore difficult to pin down in our detrended data. More precisely, we set the discount factor, β , at 0.99 and the depreciation rate, δ , at 0.025. The fraction of the final goods expenditure that is made on domestic goods, α^d , is set to 0.7, so that the implied steady state imports GDP ratio is 30%, consistently with the average over our sample. The technology parameter, ψ , is calibrated at 0.3, consistent with the value used in Lindé (2004) and Smets and Wouters (2003). As in Kollmann (2001), we refer to the estimates of Martins, Scarpetta, and Pilat (1996) to calibrate the steady state markup over marginal cost for intermediate good, ν , at 0.16, a value consistent with the estimate for the manufacturing sector in Sweden.

3.3 MCMC

A common problem in highly parametrized models is that it is impossible to directly infer the properties of the posterior. Thus, it is impossible to immediately characterize the estimates as well as any of their functions such as impulse response functions or variance decomposition. The obvious solution to this problem is to sample a given number of draws from the posterior and use these to characterize the desired statistics – this is the direct posterior simulation method as labeled in Gelman, Carlin, Stern, and Rubin (2004). In more complex models, however, direct simulation is no longer possible and it becomes necessary to employ iterative simulation algorithms. These start with a guess distribution for the posterior and through iterative jumping and an acceptance/rejection rule based on the true posterior, density converges into the true posterior distribution – this is the class of MCMC methods.

In this paper, we generate a sample of five parallel chains of 200,000 draws performing a Metropolis algorithm using a Normal as the jumping distribution. To initialize the MCMC procedure, we use importance resampling. First, we draw a sample of 1000 simulations from an approximate distribution based on a mixture of Normals with means equal to the posterior mode and variances equal to the inverse Hessian scaled, using four different factors. Then, we improve this approximation using importance resampling and using the results as starting points for the Metropolis algorithm. To ensure convergence, we twice updated the covariance matrix used for the jumping distribution. Each update was calculated after getting five different parallel chains of 200,000 draws, excluding the initial 10% and using every tenth draw. The covariance matrix used in the jump distribution is scaled to generate an acceptance ratio of about 23% for each chain. The results from the posterior estimation and MCMC draws are presented in Table 3.1.

We monitored convergence by estimating the potential scale reduction (\hat{R}), and the effective number of independent draws for the group of five chains (mn_{eff}) as suggested in Gelman, Carlin, Stern, and Rubin (2004). However, these statistics are mainly intended as a comparison of convergence across parallel chains, not within chains. To be more thorough, we followed the methods proposed in Geweke (1999) to compute the effective number of independent draws (n_{eff}) to monitor for within

chain convergence. The aforementioned statistics are presented in Table 3.2.¹²

4 Results

How different is monetary policy under a target zone and an inflation targeting regime? What is the impact of the two regimes on the economic dynamics? What is the relative importance of the different shocks in a small open economy like Sweden under these two different monetary regimes? In this section, we present the results of our inference which try to answer these questions. The first issue is addressed in the first subsection, where we report the parameter estimates. The second subsection looks into the second matter with an analysis of the response of the main variables to the different structural shocks through an impulse response analysis. The third subsection performs a variance decomposition analysis of the shocks, which is intended to address the third question. In the two latter parts, we only use 1000 draws, picked from the full sample, and compute the 5th percentile, the 95th percentile and the median.

4.1 Parameter estimates

Table 3.1 displays the results from the simulations, comparing prior with posterior moments. The estimated monetary policy rules show interesting differences between the target zone and the inflation targeting period. According to our results, monetary policy responded much more aggressively to exchange rate movements during the target zone than during the inflation targeting period. During the target zone, $\Gamma_{e,TZ}$ has a median of 3.5. However, for the exact interest rate response to the exchange rate, we need to take into account the interest rate smoothing parameter, ρ_m . Multiplying $\Gamma_{e,TZ}$ by $1 - \rho_{m,TZ}$, yields a coefficient of 0.23. This implies that a 1% deviation in exchange rates from central parity would lead the annualized interest rates to move about 91 basis points. Applying the same line of reasoning, in the free floating period we compute that a 1% quarterly change in the nominal exchange rate would move the annualized interest rate by less than 2 basis points, a fifty-fold

¹² We complemented these tests with the separated partial means test also proposed in that paper as well as a graphical analysis, which we are not presenting here but which are available upon request.

difference in response.

The estimated responses of monetary policy to output are higher during the target zone than during the inflation targeting period. A priori, we would expect that in the target zone, under the pressure to pay more attention to the exchange rate, the monetary authority would not respond as aggressively to output and inflation variations as in a flexible inflation targeting regime. However, our results show that while policy to some extent does react to output under the target zone period (median of 0.41), it reacts very little in the period of inflation targeting (median of 0.01). As concerns inflation, once we take the smoothing parameter (ρ_m) into account, a 1% increase in inflation will lead to an increase in the annualized interest rate of 10 basis points during the target zone and 18 basis points during the inflation targeting period. Thus, according to our estimation, during the inflation targeting period, the monetary authority reacted more strongly to inflation than to movements in the real economy. This finding is consistent with the Sveriges Riksbank Act, which states that the objective of monetary policy is to "maintain price stability" and suggests the attempt at rebuilding credibility and gaining the confidence of the general public.¹³

We estimate a higher value for the interest rate smoothing coefficient during the target zone (median 0.93) than during the inflation targeting period (median 0.87). A possible explanation for this result is that by keeping the interest rate stable, the central bank aimed at making the target zone regime more credible. Finally, the non-systematic component in the Taylor rule ($\varepsilon_{m,t}$) is almost 4 times more volatile during the target zone than during the inflation targeting period. These results are consistent with the findings in Adolfson, Laséen, Lindé, and Villani (2007b), and suggest that monetary policy has become more predictable and systematic after the introduction of the inflation targeting regime.¹⁴

Before proceeding, we should note that the posterior distribution of the target

¹³ Even in more recent documents of the Riksbank, output concerns only gradually creep in as credibility is being built. Heikensten and Vedrin (1998), for example, stress that there is no conflict between monetary policy long-term objective, price stability, and the mitigation of short-run output fluctuations only as long as "inflation target credibility is not weakened".

¹⁴ To check the sensitivity of our results, we also tried a different specification for the Taylor rule where we do not allow the variance of the monetary policy shock to differ across the two regimes. In this case, the estimated coefficient on inflation ($\Gamma_{p,FF}$) during the inflation targeting period is higher than that reported in Table 3.1. However, the marginal likelihood clearly speaks in favor of the specification reported in the text.

zone interest rate rule parameters on inflation and output is not too different from the prior distribution. This can be the result of a too short and not too informative sample. However, given that the priors for the target zone are set equal to those for the inflation targeting regime, there is no reason to believe that the priors influence the results. This still allows us to reasonably compare the two periods, taking into account that, given the same priors, any differences are solely attributable to the information contained in the data.

Another coefficient of significant interest is the sensitivity of the expected rate of realignment, ρ_x , which has a median of 0.13 in our simulations. This is a lower value than in Svensson (1994), which presents values consistent with a quarterly coefficient around 0.3, but mentions that its estimate, obtained by ordinary least squares or instrumental variables, should be interpreted as an upper limit.

As for other, regime independent, parameters, the intertemporal elasticity of substitution, $1/\sigma_c$, is 0.42. This value, together with an estimated consumption habit parameter, v , of 0.89 implies a lower sensitivity of consumption to changes in the real interest rate as compared to the estimates in Smets and Wouters (2003) for the Euro area. The price elasticity of foreign demand for the domestic good, η , is estimated at 1.55, thus considerably above the values estimated by Johansson (1998), but lower than the 3.0 obtained by Gottfries (2002). The capital adjustment cost, Φ , has a median of 7.6, a value lower than that calibrated by Kollmann (2001), but more in line with the view that adjustment cost are economically relevant but modest in size.

The Calvo parameters, α_p and α_w , have medians of 0.89 and 0.84, thus implying that prices are changed slightly less often than every two years, while wages are set roughly every one year and a half. Thus, according to our estimates, wages are more flexible than prices in Sweden. This result is in line with Adolfson, Laséen, Lindé, and Villani (2007b), even though their estimated level of price and wage stickiness is somewhat lower than ours.

Finally, both the labour supply shock and the realignment expectation shock processes are estimated to be quite persistent, with estimated autocorrelation coefficients of 0.99.

4.2 Impulse response functions

In this subsection, we compare the reaction of the key Swedish macro variables to different shocks in the two regimes. These responses are shown in Figures 3.2 through 3.12.¹⁵ Our findings can be summarized as five items. First, the responses to foreign shocks are generally stronger in the target zone regime than in the inflation targeting one. Second, domestic shocks generate the strongest responses of most variables under inflation targeting. Third, foreign interest rate and risk premium shocks lead to stronger responses in the target zone period, precisely because monetary policy reacts so as to defend the exchange rate parity, channeling these shocks from the financial markets to the real economy with more strength. Fourth, using the nominal interest rate, monetary policy reacts to most shocks in the inflation targeting period, except to risk premium and foreign shocks (it barely reacts to these). On the other hand, these shocks lead to significant responses of the nominal interest rate in the target zone period, as well as the realignment expectations shock. This seems consistent with what we would expect in the two regimes: in the target zone regime, monetary policy mainly reacts to exchange rate deviations from its central parity, while under inflation targeting, it has more flexibility to react to the different shocks in the economy. Fifth, the external sector plays an important role in the economy and the international transmission mechanism is significantly affected by the choice of exchange rate regime. Next, we analyze some of the responses in more detail.

An increase in the foreign interest rate (Figure 3.2) has a considerable effect on GDP, employment and capital accumulation in the target zone, but not under inflation targeting. On the other hand, the same shock induces a larger real and nominal exchange rate depreciation under inflation targeting. This can be explained in the following way. In the inflation targeting regime, the interest rate barely reacts to the higher foreign interest rate, which leads to a depreciation of the domestic currency in the short run. Given our assumption of local currency pricing, a depreciation of the home currency raises the markup of exporting firms. The foreign monetary policy tightening contracts demand abroad but at the same time the resulting depreciation induces a sizable increase in exporters' profits. Exporters are therefore able

¹⁵ Responses are presented in percentage points. The shocks are set to one standard deviation. In the plots, we present the median response, as well as the band formed by the 5th and 95th percentiles.

to charge a lower price and exports increase. Thus, this leads to a slight increase in inflation, output and employment. In the target zone period, instead, the central bank more significantly increases the domestic interest rate to prevent a large depreciation. This has contractionary effects, leading to lower output, employment, capital stock and real wages. Therefore, the two regimes imply responses that are both qualitatively and quantitatively different.

When it comes to foreign inflation shocks (Figure 3.3), the differences are more quantitative than qualitative. In particular, responses under the target zone are much more significant than under inflation targeting. A nominal shock in the foreign economy is relatively well absorbed by the exchange rate when it is allowed to float during the inflation targeting period. If, however, the nominal exchange rate is kept stable, as in the target zone, then this foreign shock has a stronger impact on the domestic economy generating inflation and output expansion (through higher export revenues in domestic currency).

Shocks to foreign output (Figure 3.4) imply an increase in foreign demand for domestic goods which boosts domestic output and employment, leading to inflation pressures. The impact on those variables is stronger but less persistent under inflation targeting than under the target zone. The reason is that, under inflation targeting, the inflationary pressures lead to a weaker currency on impact which further boosts exports and hence, output and employment.

Risk premium shocks (Figure 3.5) have a small impact in the inflation targeting period, with only inflation, wages and the exchange rate reacting to them. During the target zone, instead, the potential depreciation leads the authorities to increase the interest rate, thus generating a contraction in the real economy.

A similar pattern of responses takes place under realignment expectations shocks (Figure 3.6) in the inflation targeting regime. The only distinction is that in the latter, the variables show more inertia given the highly autocorrelated nature of this shock.

Preference shocks (Figure 3.7) boost demand and generate inflationary pressure. In response, the Riksbank raises the interest rate to contain inflation. Since the domestic currency is not allowed to depreciate in the target zone, foreign demand does not react as much as under inflation targeting and therefore, output is lower.

Positive labor supply shocks (Figure 3.8) change the intratemporal substitution

between labor and consumption. The shock produces the same qualitative effects on output, employment, capital accumulation and wages under both monetary regimes. However, the response of inflation differs across the two regimes and this cost-push shock leads to stagflation if no action is taken. Indeed, this is what happens in the target zone period where the shock generates a recession and inflation. In the inflation targeting period, the exchange rate is allowed to change and therefore, the necessary real exchange rate adjustment is more immediate. Given our assumption on the exporters' invoicing practice, the exchange rate appreciation shrinks exporters' profits much more quickly than in the target zone period. Hence, in this case, the recession takes place sooner. As employment contracts, so does consumption. This strong short-run recession actually overruns the inflationary pressures in terms of domestic price index and inflation actually falls so that the interest rate is set at lower levels. Only as wages keep increasing do the inflationary pressures occur more consistently, and the interest rate policy is eventually switched to a contractionary policy to curb inflation. Throughout the entire episode for the two regimes, capital stock falls significantly and very persistently.

A technology shock (Figure 3.9) generates similar qualitative responses in the two regimes. However, in the inflation targeting period, the domestic currency is allowed to appreciate more, leading to lower interest rates, exports, output and capital accumulation.

A monetary shock (Figure 3.10) is worth mentioning only in that it generates a stronger response in the flexible exchange rate period; as exchange rates are free to float and react, exports are more responsive (precisely because export prices change more) as are output and the remaining economy.

Finally, the two markup shocks (Figures 3.11 and 3.12) are cost push shocks which lead to a stronger reaction of the central bank during the inflation targeting regime.

4.3 Variance decomposition

This subsection analyzes the relative importance of the different shocks in the Swedish economy during the two regimes through a variance decomposition, the

results of which are presented in Tables 3.3 and 3.4.¹⁶

The variance decomposition of output highlights striking differences between the two regimes. During the target zone period, most of output variability is explained by two very persistent shocks to realignment expectations and labor supply. At a one-quarter and one-year horizon, the realignment expectation shock accounts for more than 70% of the volatility of real output. On a five-year horizon, this shock reduces its importance to 24%, while the labor supply shock explains 72% of output volatility.

In the inflation targeting period, in contrast, preferences and labour supply shocks play the main role in explaining output volatility. The first shock explains up to 23% of GDP volatility in the short run while the latter, not surprisingly given its autoregressive nature, accounts for up 97% of output volatility after five years. One interesting fact is that technological shocks are not very important in any of the monetary regimes. The fraction of output volatility explained by technology shocks is negligible, and this shock only seems to account for labor volatility in the short and medium run, especially during the inflation targeting period. At odds with the RBC paradigm, this result corroborates the findings of Galí (1999, 2004) according to which technology shocks are not a significant source of fluctuations in GDP, neither for the US nor for the Euro area.

The variance decomposition for the capital stock reveals that in the target zone period, the realignment expectations shock is even more important (above 90%), also in the long run. This is due to the strong responses of interest rates to this shock, with subsequent repercussions on the cost of capital. On the other hand, during the inflation targeting period, the main determinant of capital variability is the labor supply shock, explaining 65% of capital volatility on a quarterly horizon and 94% on a five-year horizon. Secondary factors are monetary and price markup shocks (in the short-run).

These results are perfectly consistent with the impulse response analysis performed above. As highlighted by our estimated interest rate rules, the Riksbank reacted aggressively to deviations of the exchange rate from central parity during the target zone period. A realignment expectations shock translates into a depreciation of the exchange rate and the hike in the interest rate induces declines in output,

¹⁶ Each element of the table presents the median.

employment and capital accumulation.

The price markup shock explains most of the inflation variation under both monetary regimes at every horizon, while wage markup shocks play a role only in explaining wage volatility.

Nominal exchange rate variability is mostly driven by the risk premium, realignment expectations and monetary shocks during the target zone. During the inflation targeting period, risk premium and labor supply shocks are instead the most important source of exchange rate instability at all time horizons. A similar pattern holds for the real exchange rate.

Finally, shocks to foreign variables do not make any significant contribution to economic volatility in Sweden, in any regime or at any time horizon. This seems awkward, given that exports account for about 30% of Sweden's GDP¹⁷ and foreign demand seems to be rather price sensitive. However, recalling the results from the impulse responses, the foreign sector plays a relevant role in the transmission mechanism. Moreover, besides the shocks to the foreign variables, the shocks to the expectations of realignment and the risk premium, most likely originate abroad, and those shock have a significant influence on the volatility of the economy. Therefore, the proper conclusion is not that the foreign sector is irrelevant but rather the opposite, especially during the target zone period.

5 Conclusion

The main contribution of the paper is to account for the monetary policy regime shift, occurring in 1992 after the speculative attack against the Swedish krona, and the consequent switch from a target zone regime to explicit inflation targeting. Having structurally estimated the model of the Swedish economy, we analyze its behavior the across those two regimes, and its main sources of volatility.

In the inflation targeting period, monetary policy reacts to most shocks, except the risk premium and the foreign interest rate, while these two shocks, together with the expectations of realignment, significantly drive the nominal interest rate in the target zone period. This seems consistent with common sense and a priori expectations: in the target zone, the Riksbank mainly reacted to exchange rate deviations

¹⁷ Mean over the sample period (1980:01-2002:03) considered here. Source: Statistics Sweden.

from central parity, while under inflation targeting, it had the flexibility to react to different shocks. This interpretation is confirmed by the estimated coefficients of the interest rate rules. The policy rule in the target zone is highly responsive to the exchange rate. However, the inflation targeting regime does not seem very flexible, given that the coefficients on output and exchange rate in the policy rule are rather small.

Responses of variables to foreign shocks are generally stronger under the target zone than under inflation targeting, while domestic shocks generally generate the strongest responses in the inflation targeting regime. The foreign interest rate and risk premium shocks lead to stronger responses in the target zone period, as monetary policy defends exchange rate central parity such that financial market shocks are more strongly transmitted.

Preferences and labor supply shocks are two important sources of business cycle volatility under inflation targeting, while expectations of devaluation shocks are the most important in the target zone period. The latter finding is consistent with Lindberg, Söderlind, and Svensson (1993), who show that the Swedish target zone lacked credibility most of the time. Interestingly, technology shock seems to account for very little of the overall variance, and are certainly not a main source of business cycles.

Finally, shocks to the foreign variables do not appear to generate much volatility in Swedish economic variables in any regime or at any time horizon. But the foreign sector is still very significant in the economy. It propagates other shocks, and the important shocks to risk premia and realignment expectations most likely have foreign sources.

Summing up, we conclude that the influence of different shocks is very different in the two regimes and therefore, it is important to account for the regime change in the estimated DSGE to properly capture the information in the data. If the model is estimated in the entire sample without accounting for this, we risk capturing business cycle properties that are averaged across the two periods.

We conclude with a few remarks on the limitations of our results and suggestions for future research. We find a higher degree of price and wage rigidity than studies based on microdata. The response of output after a monetary policy shock is not as hump shaped as in many other empirical works. We leave a deeper analysis of

both endogenous and exogenous components of devaluation expectations to future research. Furthermore, as a first approximation, the policy rule in the inflation targeting regime is modeled as a Taylor rule, which is not necessarily the best approximation to the actions of the Riksbank.

Given the many parameters of our model and the limited amount of data, we have chosen to only vary parameters of the Taylor rules across the two subsamples. It would be interesting to allow other parameters to differ across the two regimes to search for empirical evidence for the "Lucas critique". In particular, it would be interesting to allow for a different degree of exchange rate pass-through or a different volatility in the risk premium shocks under the two different exchange rate regimes.

Finally, Justiniano and Preston (2006a) question the ability of an estimated, structural, small open economy model to account for the considerable influence of foreign disturbances that has been identified in reduced-form studies for the Canadian economy. It would be interesting to run a similar experiment on Swedish data to understand how much of our results depend on our specific modeling choices.

Appendix

3.A Log-linearized equations

In this section, we present all log-linearized expressions, using the notation of $\hat{X}_t = \ln(X_t/X)$.

The log-linearized expressions of the final and intermediate goods sectors are given by:

$$\begin{aligned}
\hat{Z}_t &= \alpha_d \hat{Q}_t^d + (1 - \alpha_d) \hat{Q}_t^m, \\
\hat{Q}_t^d &= \hat{Z}_t - \hat{P}_t^{dr}, \\
\hat{Q}_t^m &= \hat{Z}_t - \hat{P}_t^{mr}, \\
\hat{Q}_t^x &= \hat{Y}_t^* - \eta \hat{P}_t^{xr}, \\
\hat{Y}_t &= \frac{\alpha_d(1 + \nu)}{\alpha_d(1 + \nu) + (1 - \alpha_d)} \hat{Q}_t^d + \frac{1 - \alpha_d}{\alpha_d(1 + \nu) + (1 - \alpha_d)} \hat{Q}_t^x, \\
\hat{Y}_t &= \hat{\theta}_t + \hat{K}_t + (1 - \psi) (\hat{R}_t^r - \hat{W}_t^r), \\
\hat{L}_t &= \hat{R}_t^r - \hat{W}_t^r + \hat{K}_t, \\
\hat{s}_t &= -\hat{\theta}_t + \psi \hat{R}_t^r + (1 - \psi) \hat{W}_t^r, \\
0 &= \alpha_d \hat{P}_t^{dr} + (1 - \alpha_d) \hat{P}_t^{mr}, \\
(1 + \alpha_p^2 \beta) \hat{P}_t^{xr} &= \alpha_p \beta E_t \hat{\pi}_{t+1}^* - \alpha_p \hat{\pi}_t^* + \alpha_p \hat{P}_{t-1}^{xr} + \alpha_p \beta E_t \hat{P}_{t+1}^{xr}, \\
&\quad + (1 - \alpha_p) (1 - \alpha_p \beta) [\hat{s}_t - \hat{q}_t] + \alpha_p \hat{\nu}_t, \\
(1 + \alpha_p^2 \beta) \hat{P}_t^{mr} &= \alpha_p \beta E_t \hat{\pi}_{t+1} - \alpha_p \hat{\pi}_t + \alpha_p \hat{P}_{t-1}^{mr} + \alpha_p \beta E_t \hat{P}_{t+1}^{mr} + (1 - \alpha_p) (1 - \alpha_p \beta) \hat{q}_t + \alpha_p \hat{\nu}_t, \\
\hat{\pi}_t &= \beta E_t \hat{\pi}_{t+1} + \frac{(1 - \alpha_p)(1 - \alpha_p \beta)}{\alpha_p} [\alpha_d \hat{s}_t + (1 - \alpha_d) \hat{q}_t] + \hat{\nu}_t.
\end{aligned}$$

The household first-order conditions are:

$$\begin{aligned}
0 &= \hat{u}_t + E_t \hat{\xi}_{t+1} - \hat{\xi}_t - E_t \hat{\pi}_{t+1} - \frac{\sigma_c}{1 - \nu} \left[E_t \hat{C}_{t+1} - (1 + \nu) \hat{C}_t + \nu \hat{C}_{t-1} \right], \\
\hat{u}_t &= E_t \hat{\pi}_{t+1} + [1 - \beta(1 - \delta)] E_t \hat{R}_{t+1}^r + \Phi \beta E_t \hat{K}_{t+2} - \Phi(1 + \beta) \hat{K}_{t+1} + \Phi \hat{K}_t, \\
(1 + \beta) \hat{W}_t^r &= \hat{W}_{t-1}^r + \beta E_t \hat{W}_{t+1}^r - \hat{\pi}_t + \beta E_t \hat{\pi}_{t+1} \\
&\quad + \frac{(1 - \alpha_w)(1 - \alpha_w \beta)}{\left(1 + \frac{1 + \gamma}{\gamma} \sigma_l\right) \alpha_w} \left[\sigma_c (1 - \nu)^{-1} (\hat{C}_t - \nu \hat{C}_{t-1}) + \sigma_l \hat{L}_t - \hat{W}_t^r \right] + \hat{\gamma}_t + \hat{\kappa}_t.
\end{aligned}$$

The Balance of payment is:

$$\hat{B}_t = \beta^{-1}\hat{B}_{t-1} + \hat{P}_t^{xr} + \hat{Q}_t^x - \hat{Q}_t^m.$$

Equilibrium in the goods market requires:

$$\hat{Z}_t = \left(1 - \delta \frac{K}{Z}\right) \hat{C}_t + \frac{K}{Z} \left[\hat{K}_{t+1} - (1 - \delta) \hat{K}_t\right].$$

The foreign sector is assumed to follow an exogenous VAR:

$$G_0 \begin{bmatrix} \hat{Y}_t^* \\ \hat{\pi}_t^* \\ \hat{i}_t^* \end{bmatrix} = G_1 \begin{bmatrix} \hat{Y}_{t-1}^* \\ \hat{\pi}_{t-1}^* \\ \hat{i}_{t-1}^* \end{bmatrix} + \begin{bmatrix} \varepsilon_y^* \\ \varepsilon_p^* \\ \varepsilon_i^* \end{bmatrix},$$

The monetary policy rule during the target zone is:

$$\hat{i}_t = \rho_{m,TZ} \hat{i}_{t-1} + (1 - \rho_{m,TZ}) \left[\Gamma_{p,TZ} \hat{\pi}_t + \Gamma_{y,TZ} \hat{Y}_t / 4 + \Gamma_{e,TZ} \hat{e}_t \right] + \varepsilon_{m_{TZ},t}$$

while the uncovered interest parity condition takes the following expression:

$$\hat{i}_t = \hat{i}_t^* + E_t \hat{e}_{t+1} + (\rho_x - 1) \hat{e}_t + \rho_s \hat{s}_t + \rho_q \hat{q}_t + g_t - \omega \hat{B}_t + \zeta_t.$$

The monetary policy rule during the inflation targeting period is:

$$\hat{i}_t = \rho_{m,FF} \hat{i}_{t-1} + (1 - \rho_{m,FF}) \left[\Gamma_{p,FF} \hat{\pi}_t + \Gamma_{y,FF} \hat{Y}_t / 4 + \Gamma_{e,FF} \Delta \hat{e}_t \right] + \varepsilon_{m_{FF},t},$$

while the uncovered interest parity condition takes the following expression:

$$\hat{i}_t = \hat{i}_t^* + E_t \hat{e}_{t+1} - \hat{e}_t - \omega \hat{B}_t + \zeta_t.$$

3.B Data

The series were collected through the DRI-Webabstract from the IMF International Financial Statistics database.

For the interest rate, we used the series L60C, which refers to the treasury bills rate or the equivalent. Due to the lack of that series for Norway, Japan and Finland, we use the money market rate, series L60B. For Denmark, we used the series of three-month treasury bills from the Danish MONA data bank. For Sweden, the series L60B is discontinued from 2002 onwards and thus, we decided to use the series L60A which corresponds to the Repo rate used in the open market operations.

For the exchange rates, we used the series LAE, which represents the end of period nominal exchange rate of each national currency per USD.

For the price levels, we used L64, referring to the Consumer Price Index (CPI).

We collected data for nominal GDP through series L99B, which was not seasonally adjusted for Sweden, Norway and Finland and seasonally adjusted (SA) for all the remaining countries. For converting this into real GDP, we collected series for the GDP deflator with a base year in 1995, series L99BI (once more SA for all except those three countries). Then, we generated the series of real GDP. For the series that were not seasonally adjusted, we used the X12 filter incorporated in the Eviews econometric package (using additive method – the multiplicative method was tried and essentially yielded the same results). While plotting the series for the nominal GDP series for Great Britain and France, we also noticed some seasonality at the end of the sample which might be due to some problem in the data; hence, we decided to also run the X12 filter on these series. Note that for the deflator of Norway, there was not much evidence of seasonal adjustment but nevertheless, we used the filter to keep it consistent across series. For Denmark, the IMF/IFS data was incomplete and therefore, we used the real GDP from the Danish MONA data bank (also with a deflator base in 1995). The series was originally in annualized terms (multiplied by 4), which we reversed.

For the wage in Sweden, we used a hourly wages series created by Kent Friberg for Sveriges Riksbank (for more information about this series, we refer to Friberg (2003)). The series was seasonally adjusted using the same method as for the other variables already mentioned.

The exchange rate is defined as the number of Swedish kronor per foreign cur-

rency. The trade weights were obtained from two different sources. For the first part of the sample, we have exact weights provided in Lindberg and Soderlind (1994) and for the second part, we got the weights from the Swedish National Institute of Economic Research. The methodologies are slightly different but hopefully similar enough for us to be able to apply the weights at the same time, since they are the only ones available. All weights are computed yearly in April. For the first part of the sample, Lindberg and Soderlind (1994) mention that the weights take effect in the second quarter of each year; hence, we keep the same periodicity over the entire sample. Given that we do not have the weights for the last year, 2002, we will use the weights of 2001 for that year.

3.C Tables and Figures

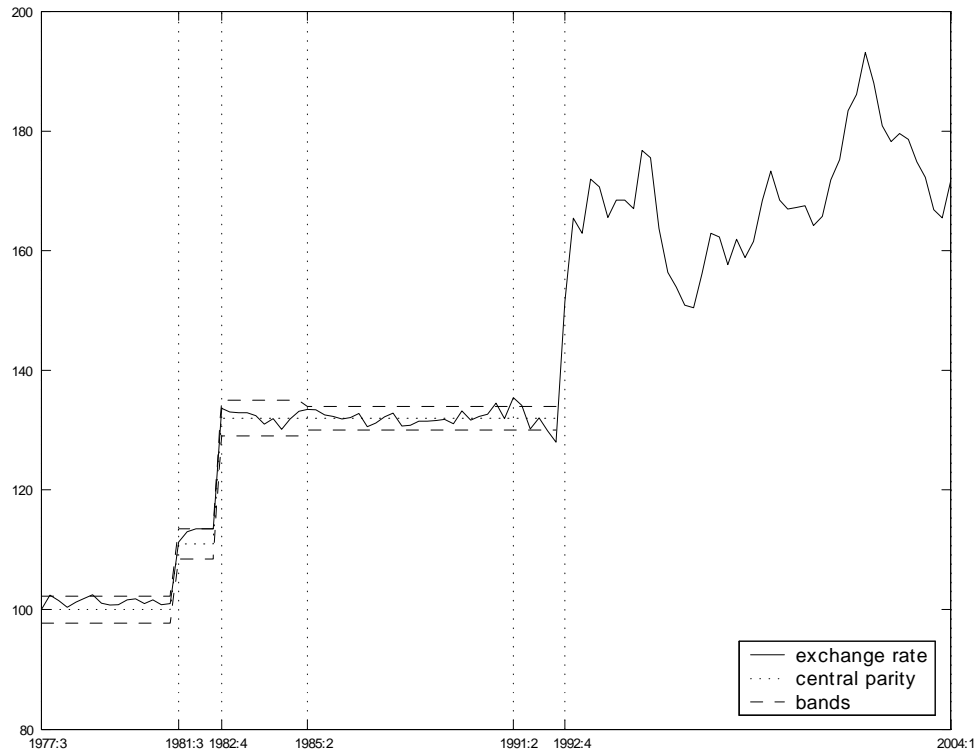


Figure 3.1: Swedish krona

Table 3.1: Parameter estimates

	Dist.	Prior				Posterior				
		5%	Median	95%	Mode	Mean	SE	5%	Median	95%
η	i-gamma	1.081	1.463	2.046	1.457	1.557	0.160	1.307	1.549	1.831
α_p	beta	0.583	0.775	0.910	0.890	0.888	0.012	0.867	0.888	0.907
α_w	beta	0.583	0.775	0.910	0.814	0.837	0.030	0.785	0.838	0.885
σ_c	normal	1.342	2.000	2.658	2.372	2.381	0.359	1.794	2.380	2.971
σ_l	normal	0.342	1.000	1.658	1.110	1.122	0.363	0.542	1.113	1.733
Φ	gamma	3.416	9.180	19.384	7.041	7.743	1.457	5.604	7.607	10.315
ν	beta	0.524	0.707	0.853	0.878	0.887	0.036	0.823	0.891	0.939
ω	gamma	0.002	0.004	0.006	0.002	0.003	0.001	0.002	0.003	0.004
$\Gamma_{p,TZ}$	gamma	0.683	1.836	3.877	1.404	1.654	0.747	0.632	1.546	3.045
$\Gamma_{p,FF}$	gamma	0.683	1.836	3.877	1.148	1.468	0.340	1.130	1.382	2.099
$\Gamma_{y,TZ}$	gamma	0.205	0.551	1.163	0.319	0.440	0.221	0.147	0.406	0.854
$\Gamma_{y,FF}$	gamma	0.205	0.551	1.163	0.005	0.014	0.011	0.003	0.011	0.034
$\Gamma_{e,TZ}$	gamma	0.613	2.569	6.859	2.857	3.732	1.467	1.843	3.477	6.479
$\Gamma_{e,FF}$	gamma	0.613	2.569	6.859	0.018	0.036	0.024	0.007	0.031	0.081
$\rho_{m,TZ}$	beta	0.617	0.817	0.941	0.930	0.930	0.027	0.878	0.934	0.966
$\rho_{m,FF}$	beta	0.617	0.817	0.941	0.856	0.869	0.029	0.820	0.871	0.914
$\sigma_{m,TZ}$	i-gamma	0.002	0.006	0.028	0.005	0.006	0.001	0.004	0.005	0.007
$\sigma_{m,FF}$	i-gamma	0.002	0.006	0.028	0.001	0.002	0.000	0.001	0.002	0.002
ρ_x	gamma	0.104	0.228	0.426	0.109	0.132	0.052	0.058	0.125	0.228
ρ_ξ	beta	0.505	0.834	0.981	0.299	0.2995	0.095	0.152	0.295	0.464
ρ_θ	beta	0.505	0.834	0.981	0.789	0.782	0.053	0.691	0.784	0.864
ρ_ζ	beta	0.505	0.834	0.981	0.668	0.657	0.047	0.576	0.660	0.729
ρ_κ	beta	0.505	0.834	0.981	0.999	0.999	0.002	0.994	0.999	0.999
ρ_g	beta	0.505	0.834	0.981	0.999	0.994	0.005	0.985	0.996	0.999
σ_ξ	i-gamma	0.002	0.006	0.028	0.329	0.393	0.127	0.232	0.370	0.632
σ_θ	i-gamma	0.002	0.006	0.028	0.020	0.020	0.002	0.018	0.020	0.023
σ_ζ	i-gamma	0.002	0.006	0.028	0.011	0.012	0.002	0.010	0.012	0.015
σ_κ	i-gamma	0.002	0.006	0.028	0.001	0.001	0.000	0.001	0.001	0.001
σ_ν	i-gamma	0.002	0.006	0.028	0.007	0.007	0.001	0.006	0.007	0.008
σ_γ	i-gamma	0.002	0.006	0.028	0.008	0.009	0.001	0.008	0.009	0.011
σ_g	i-gamma	0.002	0.006	0.028	0.004	0.005	0.001	0.004	0.005	0.007

Table 3.2: Convergence

	\hat{R}	mn_{eff}	$n_{eff}(1)$	$n_{eff}(2)$	$n_{eff}(3)$	$n_{eff}(4)$	$n_{eff}(5)$
η	1.0002	9480	613	583	570	424	552
α_p	1.0015	1690	642	500	376	449	457
α_w	1.0012	2076	316	321	480	284	325
σ_c	1.0007	3416	586	695	519	716	702
σ_l	1.0008	2978	347	688	473	479	559
Φ	1.0008	3175	586	370	415	364	409
ν	1.0009	2786	287	253	268	210	272
ω	1.0021	1177	639	416	590	489	496
$\Gamma_{p,TZ}$	1.0013	1946	467	536	513	410	225
$\Gamma_{p,FF}$	1.0021	1179	420	215	367	242	212
$\Gamma_{y,TZ}$	1.0015	1645	348	357	573	426	499
$\Gamma_{y,FF}$	1.0018	1393	552	295	509	353	282
$\Gamma_{e,TZ}$	1.0018	1395	235	180	307	224	180
$\Gamma_{e,FF}$	1.0002	10439	867	806	547	574	851
$\rho_{m,TZ}$	1.0019	1310	289	221	438	228	186
$\rho_{m,FF}$	1.0001	19384	412	297	403	266	319
$\sigma_{m,TZ}$	1.0010	2339	355	522	417	483	455
$\sigma_{m,FF}$	1.0010	2542	810	927	485	305	668
ρ_x	1.0007	3508	538	432	501	390	533
ρ_ξ	1.0004	5709	641	480	428	385	353
ρ_θ	1.0018	1359	439	576	539	675	622
ρ_ζ	1.0015	1636	672	524	375	481	530
ρ_κ	1.0015	1656	344	284	358	130	377
ρ_g	1.0007	3296	861	315	378	241	245
σ_ξ	1.0005	5077	359	243	336	260	290
σ_θ	1.0010	2408	523	511	651	358	570
σ_ζ	1.0018	1399	801	578	484	332	462
σ_κ	1.0007	3372	350	402	597	284	559
σ_ν	1.0002	9235	444	744	543	482	446
σ_γ	1.0009	2702	538	482	605	483	567
σ_g	1.0003	6855	824	258	459	442	554

Table 3.3: Variance decomposition for the target zone period

	Pref.	Tech.	Mon.	Foreign inflation	Foreign output	Foreign interest rate	Risk premium	Labor supply	Price markup	Wage markup	Realign. Exp.
1 quarter											
Y	0.051	0.000	0.012	0.015	0.001	0.004	0.076	0.009	0.045	0.000	0.780
L	0.039	0.229	0.009	0.011	0.000	0.003	0.058	0.007	0.035	0.000	0.598
K	0.000	0.000	0.012	0.007	0.000	0.004	0.086	0.001	0.015	0.000	0.872
π	0.001	0.012	0.000	0.006	0.001	0.000	0.000	0.041	0.928	0.002	0.007
i	0.000	0.000	0.384	0.000	0.001	0.004	0.409	0.000	0.007	0.000	0.185
e	0.000	0.000	0.214	0.000	0.001	0.005	0.495	0.000	0.001	0.000	0.272
q	0.000	0.001	0.180	0.014	0.000	0.005	0.421	0.006	0.099	0.000	0.258
4 quarters											
Y	0.044	0.005	0.004	0.019	0.000	0.003	0.039	0.135	0.026	0.002	0.716
L	0.0475	0.121	0.003	0.018	0.000	0.003	0.033	0.143	0.025	0.002	0.593
K	0.002	0.000	0.003	0.006	0.001	0.004	0.051	0.001	0.010	0.000	0.920
π	0.001	0.016	0.000	0.018	0.002	0.000	0.000	0.162	0.777	0.005	0.014
i	0.001	0.000	0.107	0.001	0.003	0.006	0.391	0.000	0.002	0.000	0.483
e	0.000	0.000	0.227	0.000	0.001	0.005	0.409	0.001	0.001	0.000	0.339
q	0.001	0.009	0.126	0.097	0.000	0.003	0.237	0.099	0.137	0.003	0.266
20 quarters											
Y	0.008	0.003	0.001	0.008	0.000	0.001	0.006	0.719	0.005	0.003	0.244
L	0.010	0.022	0.001	0.007	0.000	0.001	0.006	0.807	0.005	0.003	0.138
K	0.007	0.001	0.000	0.006	0.000	0.002	0.010	0.036	0.004	0.001	0.928
π	0.001	0.013	0.000	0.021	0.003	0.001	0.000	0.341	0.593	0.004	0.019
i	0.004	0.000	0.047	0.001	0.005	0.004	0.187	0.001	0.001	0.000	0.746
e	0.000	0.000	0.210	0.002	0.001	0.005	0.392	0.018	0.002	0.000	0.342
q	0.000	0.005	0.025	0.045	0.001	0.001	0.050	0.750	0.037	0.004	0.072

Table 3.4: Variance decomposition for the inflation targeting period

	Prof.	Tech.	Mon.	Foreign inflation	Foreign output	Foreign interest rate	Risk premium	Labor supply	Price markup	Wage markup
1 quarter										
<i>Y</i>	0.231	0.001	0.064	0.005	0.006	0.000	0.001	0.531	0.151	0.000
<i>L</i>	0.128	0.439	0.035	0.003	0.004	0.000	0.000	0.296	0.085	0.000
<i>K</i>	0.014	0.001	0.161	0.001	0.000	0.000	0.000	0.647	0.167	0.000
π	0.013	0.016	0.004	0.000	0.000	0.000	0.004	0.035	0.921	0.004
<i>i</i>	0.009	0.007	0.517	0.000	0.000	0.001	0.015	0.039	0.396	0.002
<i>e</i>	0.014	0.000	0.053	0.016	0.002	0.015	0.464	0.424	0.002	0.000
<i>q</i>	0.011	0.000	0.051	0.004	0.002	0.015	0.469	0.407	0.031	0.000
4 quarters										
<i>Y</i>	0.144	0.006	0.031	0.004	0.003	0.000	0.001	0.745	0.056	0.002
<i>L</i>	0.122	0.197	0.023	0.004	0.003	0.000	0.001	0.596	0.044	0.002
<i>K</i>	0.006	0.001	0.127	0.001	0.000	0.000	0.000	0.741	0.118	0.000
π	0.033	0.026	0.007	0.000	0.001	0.001	0.005	0.082	0.828	0.010
<i>i</i>	0.041	0.027	0.449	0.000	0.001	0.001	0.013	0.134	0.300	0.010
<i>e</i>	0.021	0.000	0.053	0.025	0.002	0.014	0.267	0.608	0.001	0.000
<i>q</i>	0.013	0.001	0.051	0.002	0.002	0.014	0.291	0.587	0.027	0.001
20 quarters										
<i>Y</i>	0.014	0.002	0.004	0.000	0.000	0.000	0.000	0.973	0.004	0.002
<i>L</i>	0.017	0.017	0.003	0.001	0.000	0.000	0.000	0.956	0.004	0.005
<i>K</i>	0.002	0.003	0.028	0.000	0.000	0.000	0.000	0.944	0.016	0.003
π	0.055	0.025	0.007	0.000	0.001	0.001	0.005	0.122	0.755	0.014
<i>i</i>	0.159	0.034	0.255	0.000	0.001	0.001	0.007	0.326	0.146	0.032
<i>e</i>	0.041	0.003	0.022	0.032	0.002	0.005	0.060	0.820	0.004	0.002
<i>q</i>	0.010	0.001	0.021	0.001	0.001	0.005	0.083	0.864	0.009	0.001

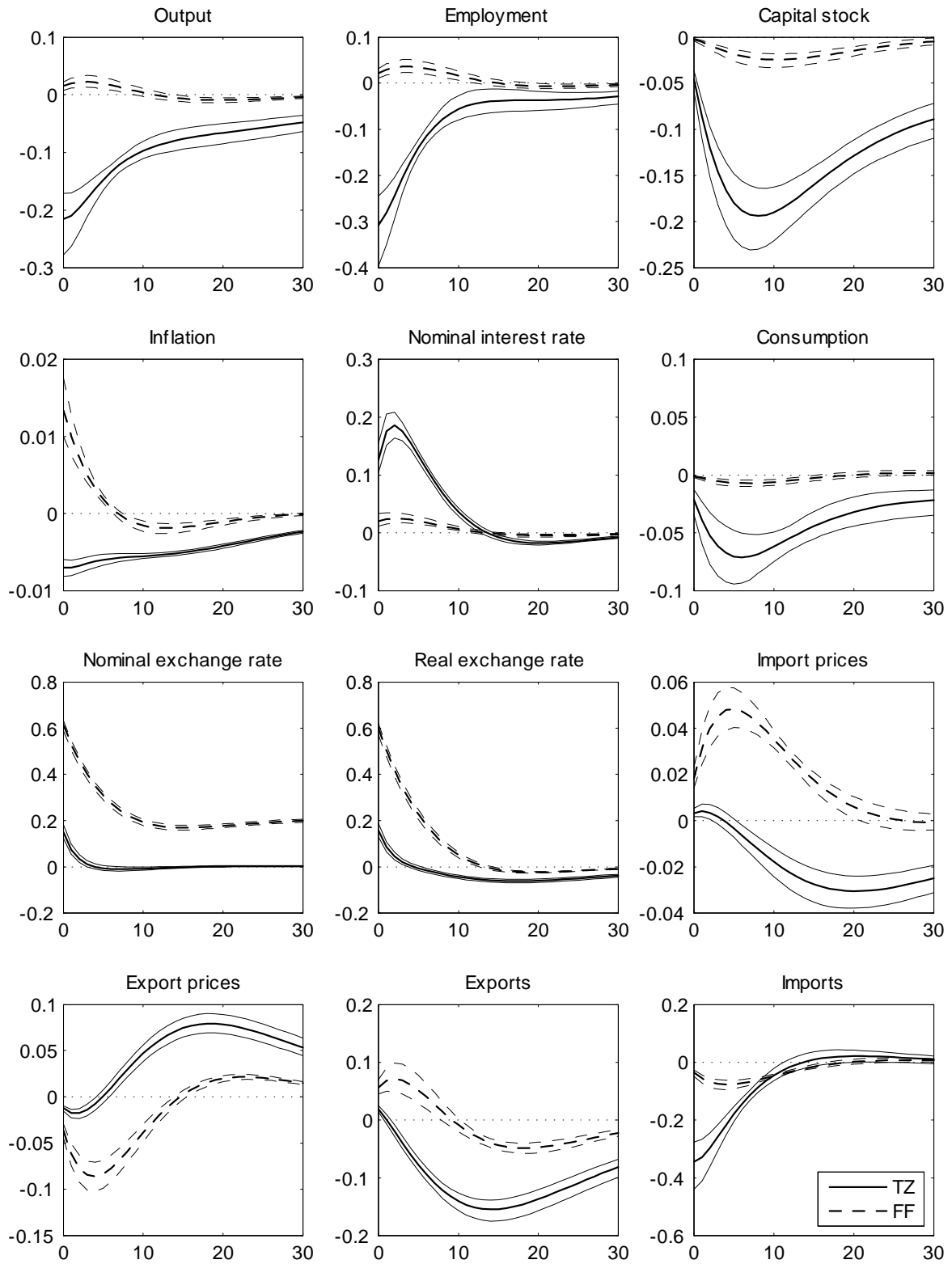


Figure 3.2: Responses to a foreign interest shock

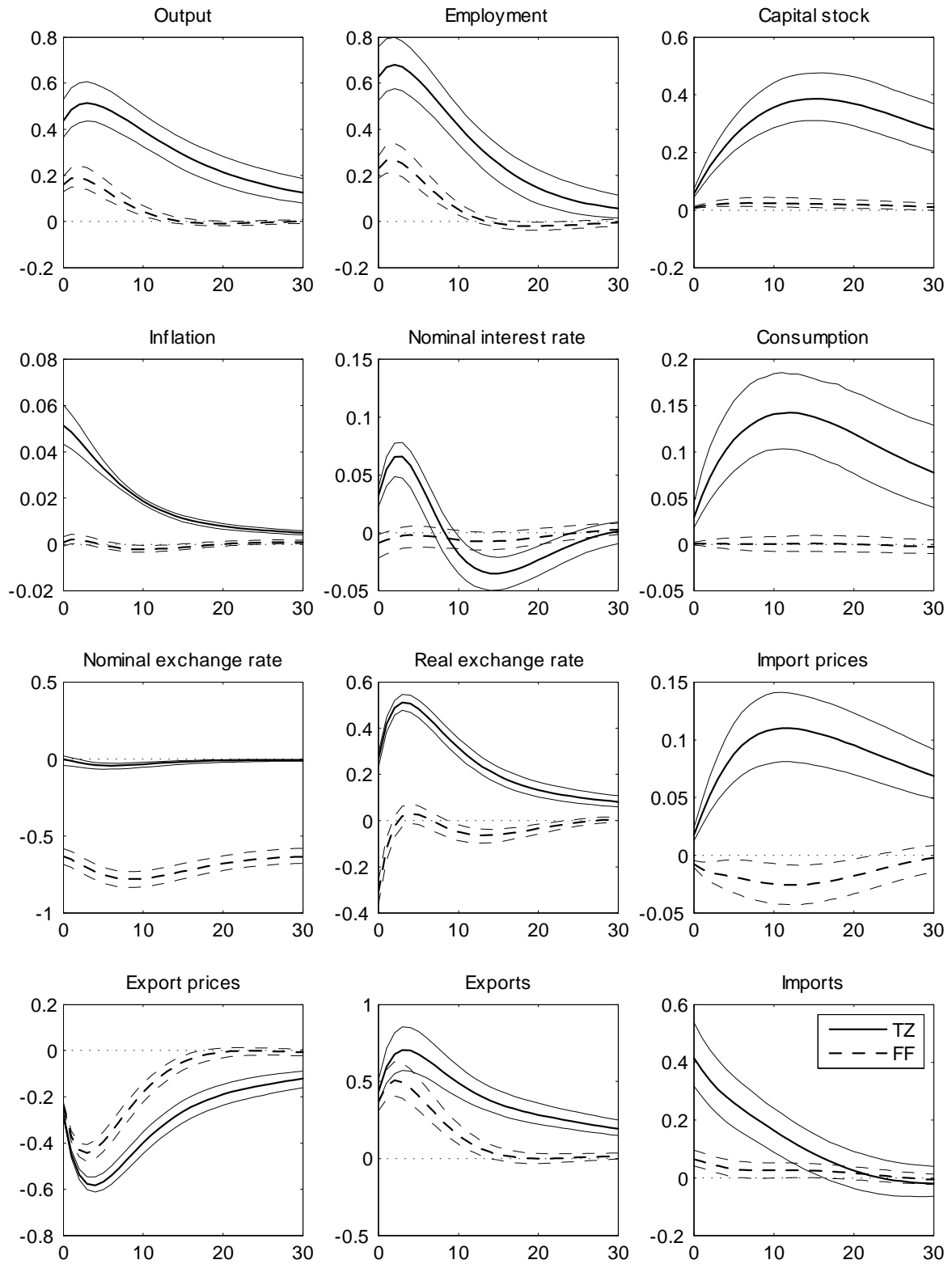


Figure 3.3: Responses to a foreign inflation shock

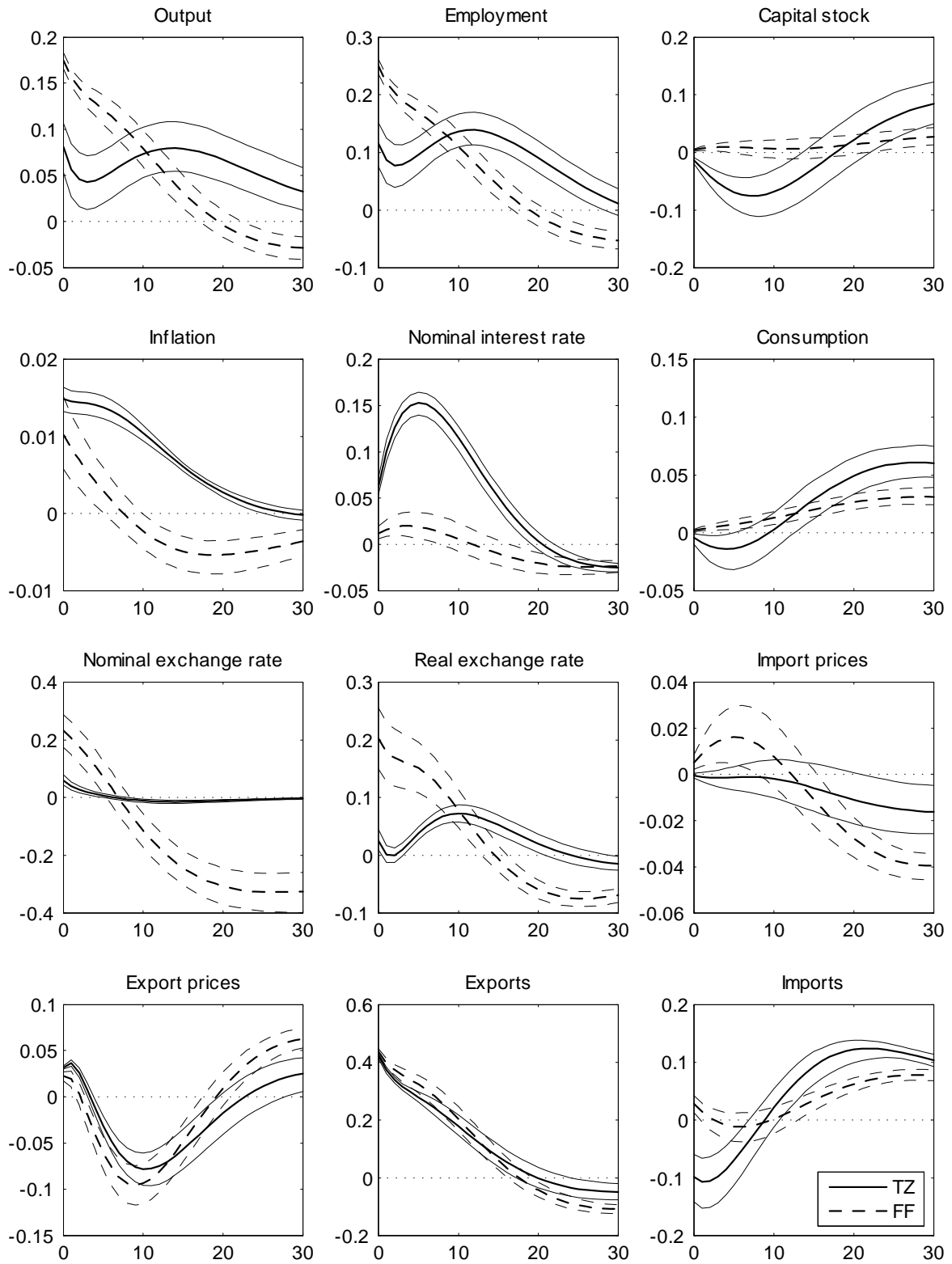


Figure 3.4: Responses to a foreign output shock

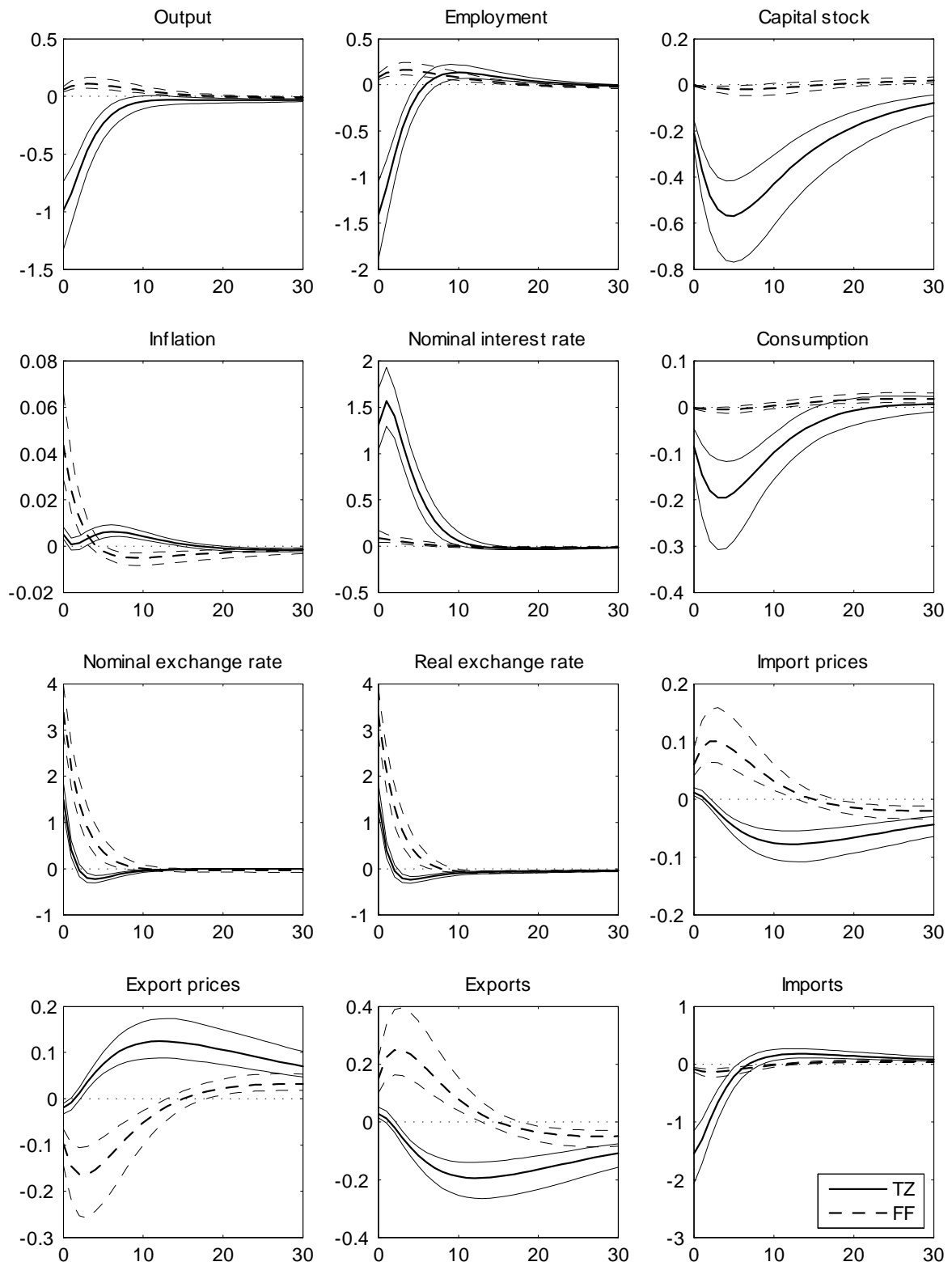


Figure 3.5: Responses to a risk premium shock

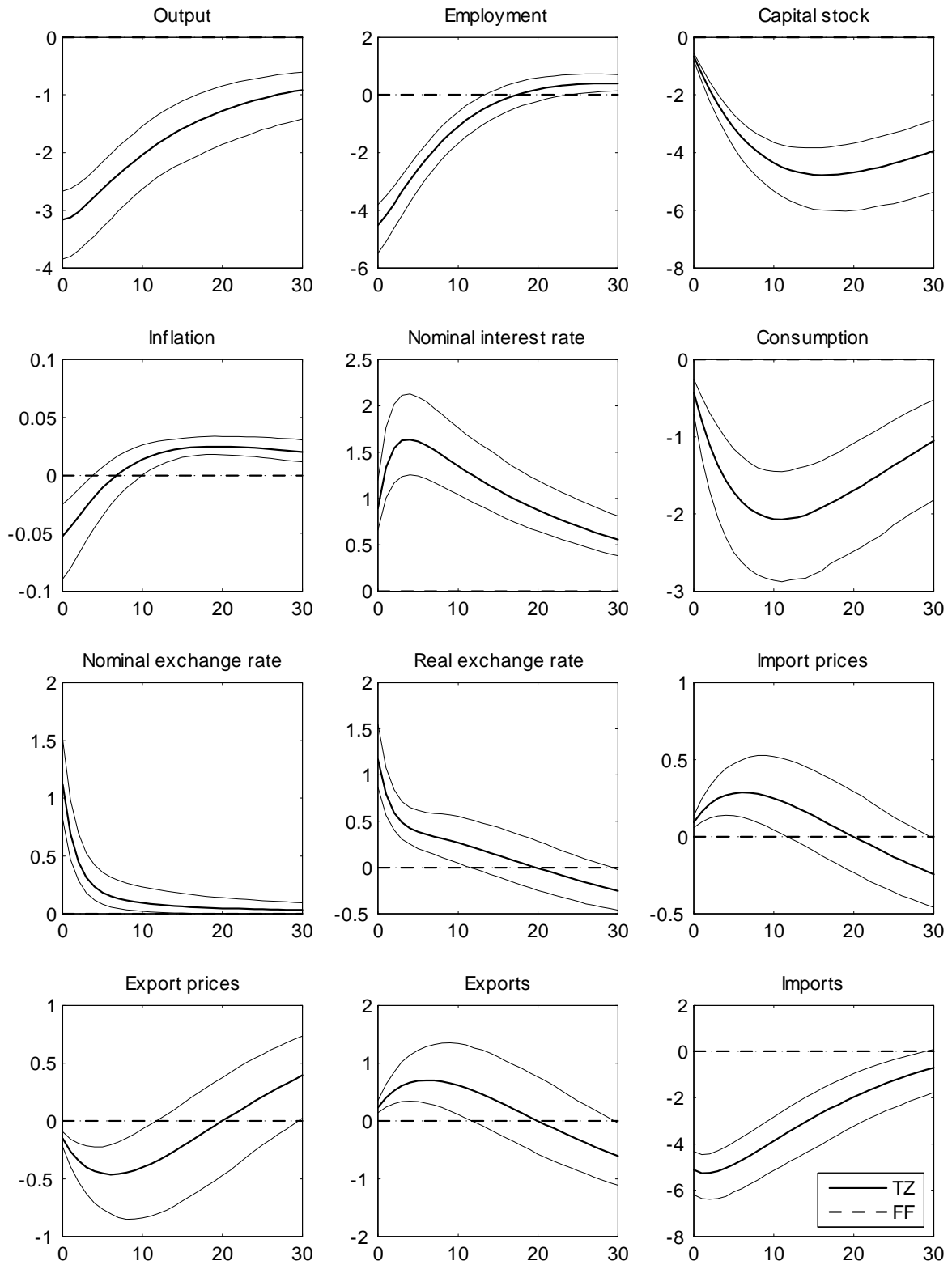


Figure 3.6: Responses to realignment expectations shock

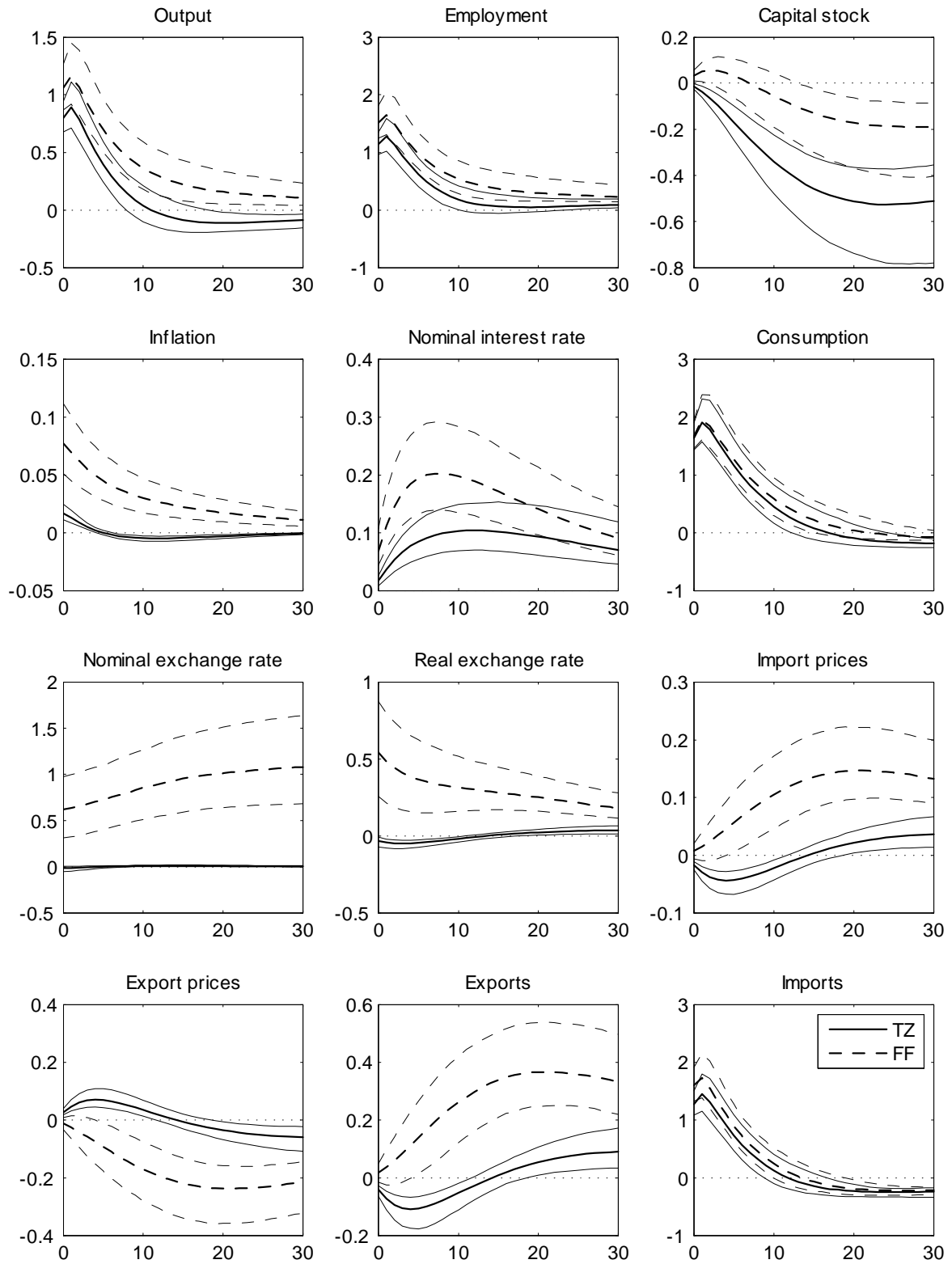


Figure 3.7: Responses to a preferences shock

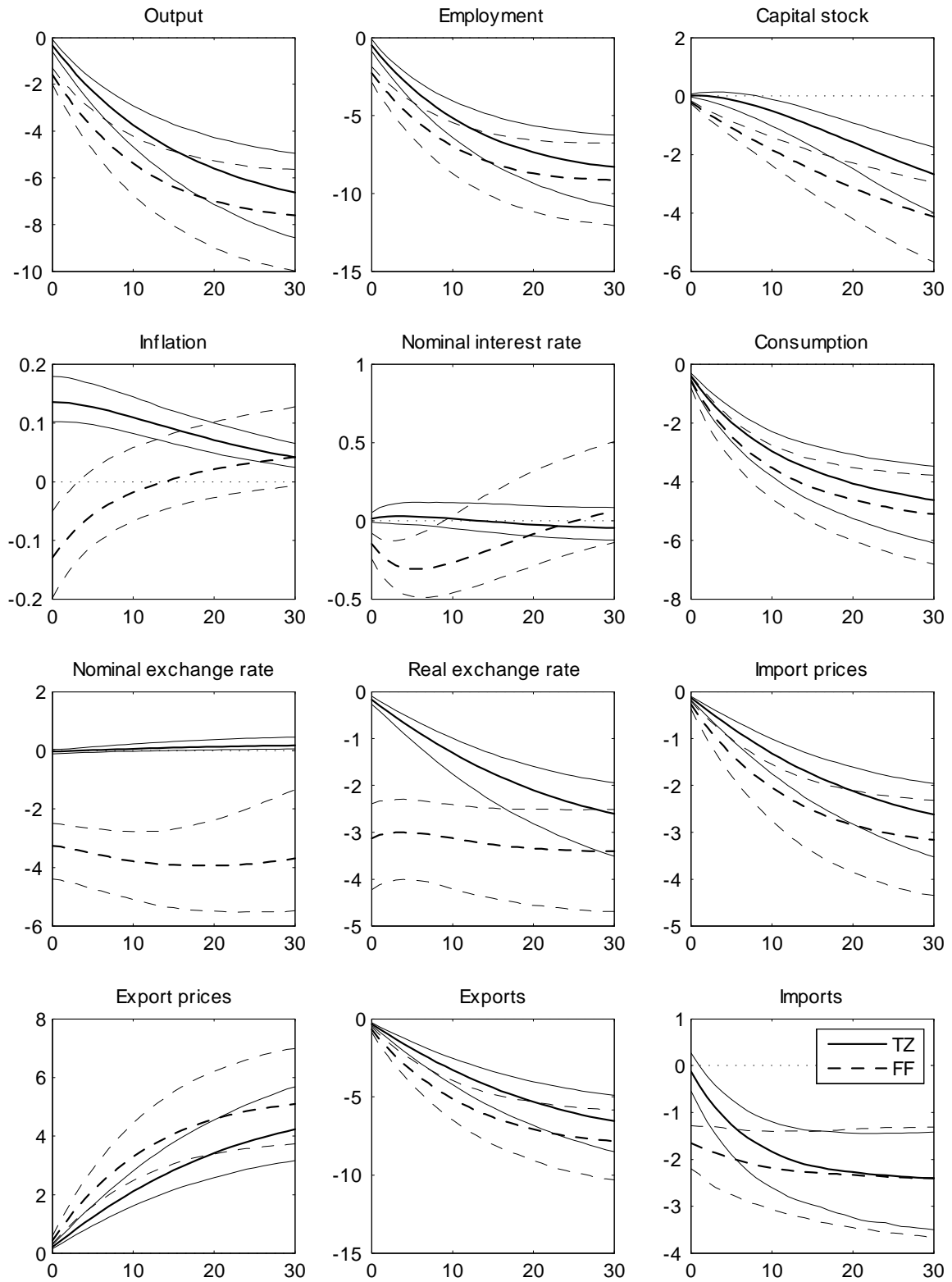


Figure 3.8: Responses to a labor supply shock

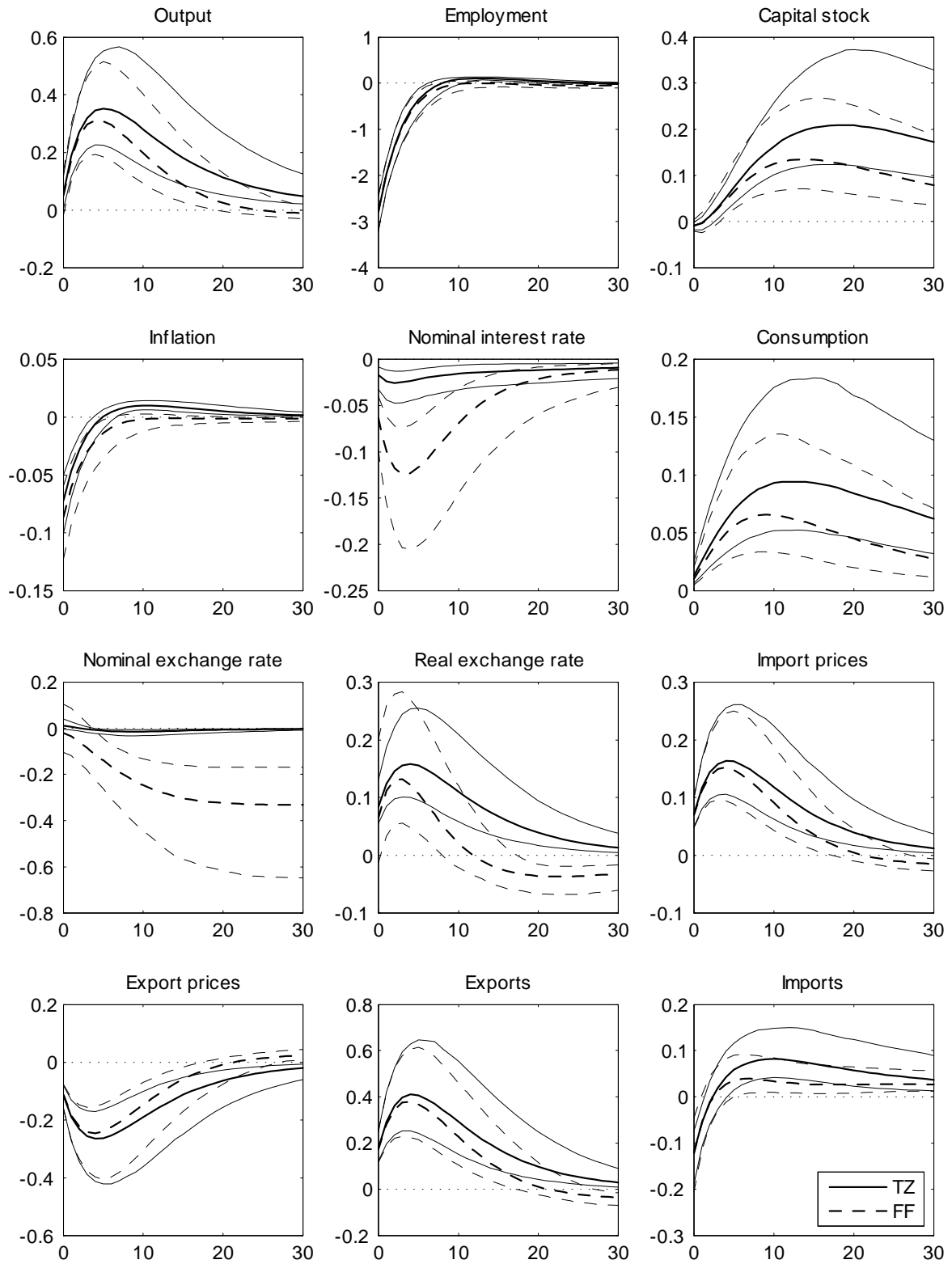


Figure 3.9: Responses to a technology shock

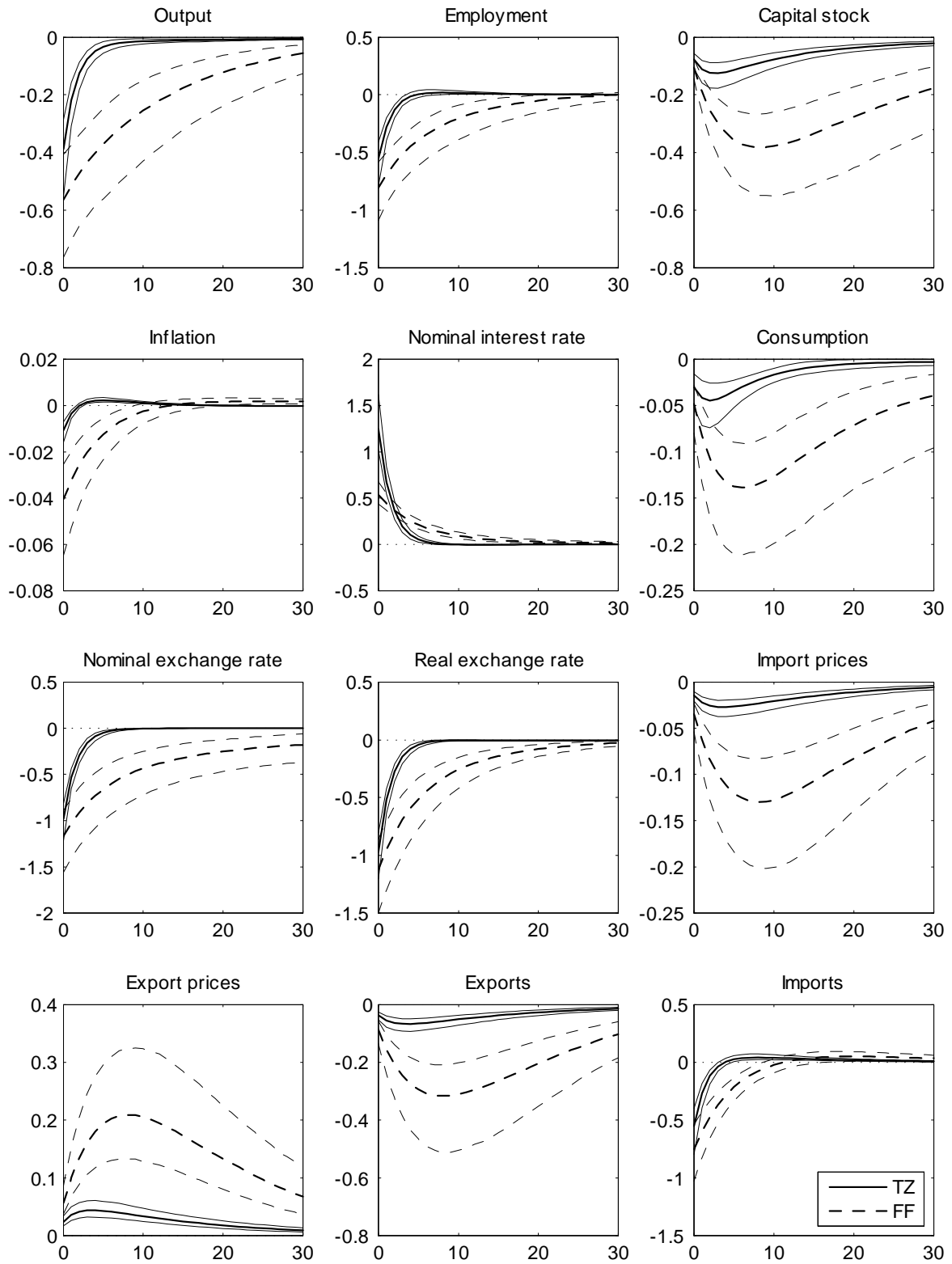


Figure 3.10: Responses to a monetary shock

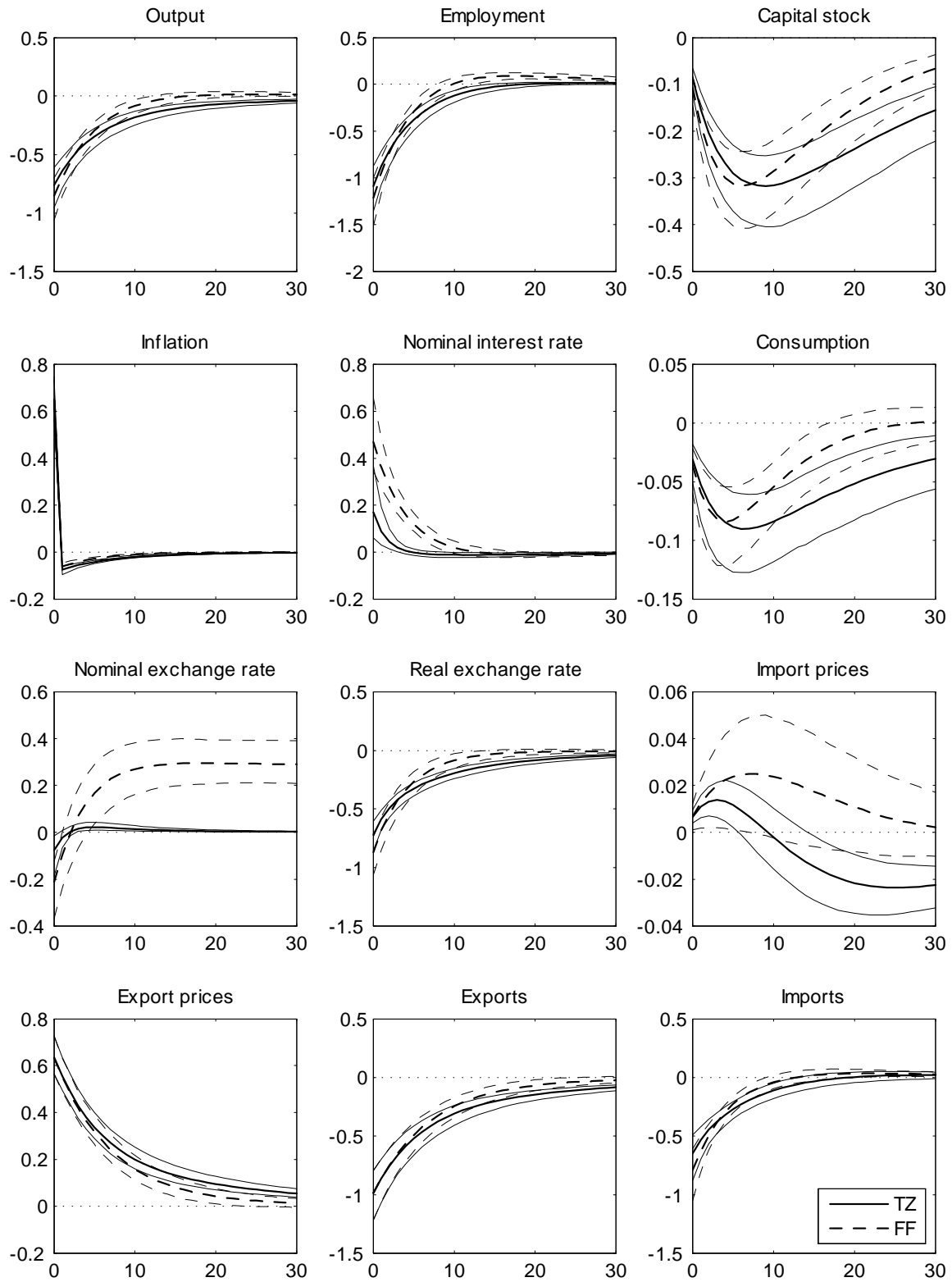


Figure 3.11: Responses to a price markup shock

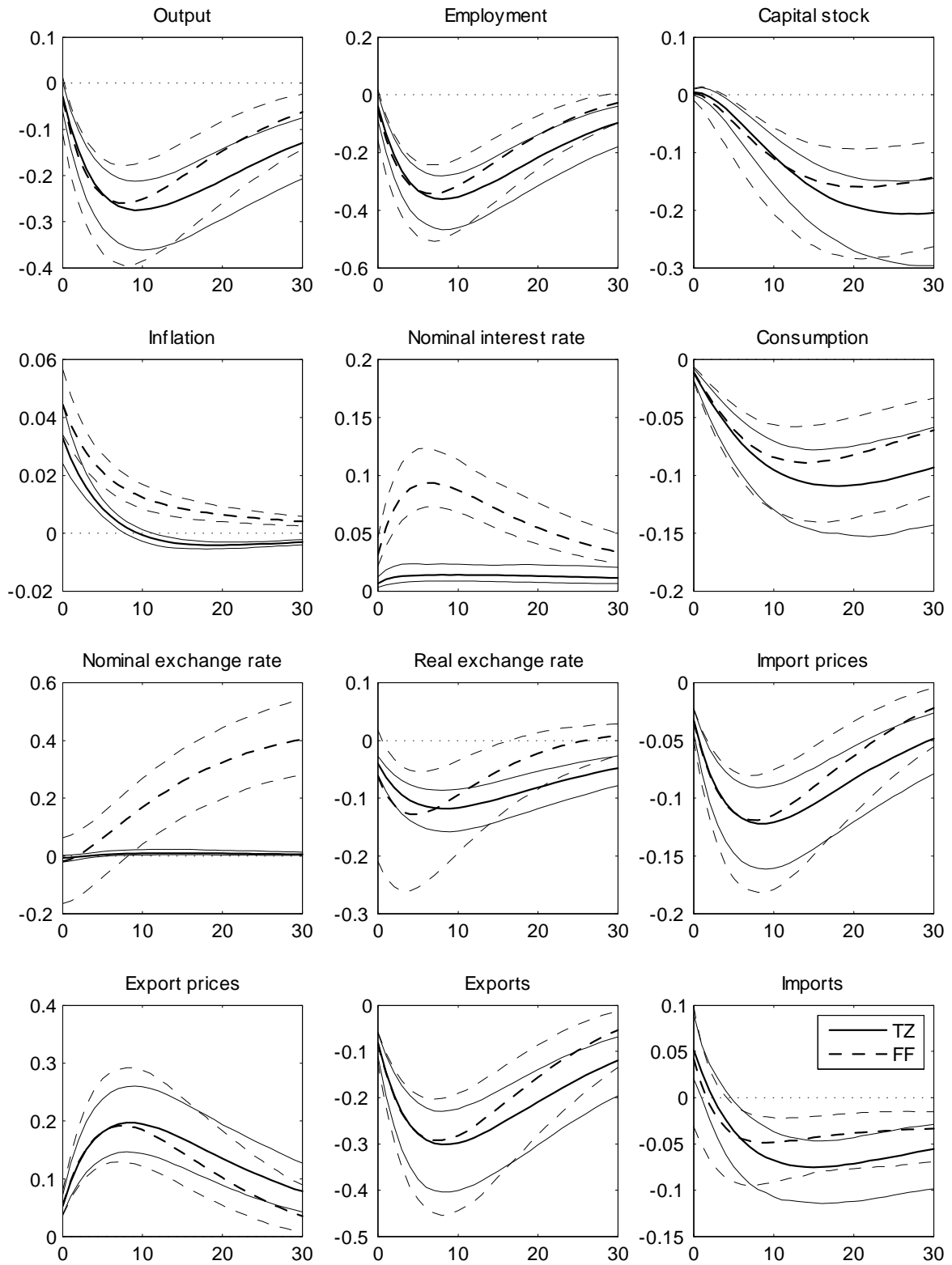


Figure 3.12: Responses to a wage markup shock

Chapter 4

Do Central Banks React to House Prices? *

"Fed debates pricking the U.S. housing 'bubble' "

The New York Times, 31 May 2005

"House price slide puts rates on hold"

The Independent 1, April 2005

1 Introduction

In the last few decades, house prices have undergone major medium-run fluctuations in many industrialized economies. Boom-bust cycles in house prices, coupled with a substantial increase in household indebtedness, have drawn the attention of both policymakers and academics towards the developments in housing markets and their impact on economic activity and on financial stability. Real house prices have risen more than 30% in the U.S. since 1995 (Figure 4.1). In the U.K., house prices peaked in 1989, lost almost 40% of their value by 1995, and have continuously increased since then (Figure 4.2).¹ The experience of Japan is also dramatic. Property prices

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¹ The financial liberalization of mortgage lending institutions in the 1980s contributed to the increase in housing prices during this period.

increased almost 40% in the five years before 1991 and have fallen since then (Figure 4.3). Since borrowing for housing constitutes the largest part of households' debt in most countries, the increase in indebtedness has made the overall macroeconomic situation more exposed to house price fluctuations. In this context, two kinds of questions have been posed in the policy debate:

1. Should central banks react to asset prices?
2. Do central banks respond to house prices? And if so, what are the business cycle implications of a central bank reacting to house prices?

In this paper, we take a positive rather than normative stand and thus address the second question. Specifically, we ask whether house prices entered directly in the monetary policy rule of the U.S. Fed, the Bank of Japan and the Bank of England. The main contributions of the paper are twofold. First, we add to the debate on monetary policy and asset prices by performing a rigorous structural estimation and formal model comparison. Using this approach, we are also able to investigate the business cycle implications of a central bank reacting to house prices. Second, we contribute to the scarce empirical literature on estimated DSGE models for the U.K. and Japan. Our estimated models are used to identify the shocks behind the business cycles of these two economies.

Modeling-wise, we study the response of central banks in an environment where credit constrained agents borrow against their collateral, thereby amplifying business cycle fluctuations. We structurally estimate the model with Bayesian methods using data between 1983Q1-2006Q4 for the U.S. and the U.K. and between 1970Q1-1995Q4 for Japan.² The results show that house price movements did not play a separate role in the Fed reaction function in the last twenty years, while they did in the U.K. and Japan.

A large academic literature studies theoretically the optimal response of central banks to asset prices. Among others, Bernanke and Gertler (2001) argue that inflation targeting policymakers should not respond to asset prices, except insofar as they signal changes in expected inflation. On the other hand, Cecchetti, Genberg,

² We do not consider data after 1995 in the case of Japan as the nominal interest rate has been close to its zero lower bound since then.

Lipsky, and Wadhvani (2000) arrive at the opposite conclusion and argue that central banks can improve macroeconomic performance by responding to asset price misalignments. Both Bernanke and Gertler (2001) and Cecchetti, Genberg, Lipsky, and Wadhvani (2000) conduct their optimal policy analysis in frameworks where asset price booms and busts exacerbate output fluctuations in response to aggregate shocks via their effect on firms' balance sheets. Moreover, both papers focus on stock market bubbles. Closer to the spirit of Kiyotaki and Moore (1997), Mendicino and Pescatori (2004) and Monacelli (2006) study optimal monetary policy in a model where impatient households borrow in nominal terms using real estate as collateral. Mendicino and Pescatori (2004) suggest that a positive reaction to house prices is welfare reducing. Monacelli (2006) finds that the Ramsey-optimal policy is an intermediate case between strict nondurables inflation targeting and strict durables price targeting.

Policymakers also hold contrasting views on this issue. For instance, Charles Goodhart, a former member of the Bank of England's Monetary Policy Committee, argues that central banks should track a broader price index which includes the prices of assets, such as houses and equities. However, Filardo (2000) concludes that adopting Goodhart's recommendation would not improve U.S. economic performance since asset prices might contain unreliable information about future inflation.

Fewer studies have tackled the positive empirical question and estimated central banks' reaction functions with asset prices. Bernanke and Gertler (1999) apply GMM methods to estimate Taylor type rules for the Federal Reserve and the Bank of Japan. Their estimated response coefficient on asset price is not significant over the period 1979-1997, neither for the U.S. nor for Japan. However, according to their estimates, the Bank of Japan reinforced the asset price boom by strongly reacting to stock returns with a negative coefficient during the bubble period (1979-1989) and attempting to stabilize the stock market after that date reacting with a positive coefficient. Rigobon and Sack (2003) point out that adding stock prices to Taylor rules creates an endogeneity problem. Moreover, they stress that addressing such a problem through instrumental variables is quite a complex task since it would be difficult to find instruments that affect the stock market without having an impact on interest rates. Using an identification strategy that relies on heteroskedasticity

in interest rates and stock returns, they show that in the U.S., a 5% rise in stock returns increases the likelihood of a 25 basis points tightening by more than 50%. Using a different identification strategy and allowing for nonlinearities in the central bank response to asset prices, D'Agostino, Sala, and Surico (2005) show that the Fed reacts much more strongly to the stock market index during periods of high asset prices volatility.

Instead of dealing with the endogeneity problem that would arise estimating Taylor rules with asset prices in a univariate setting, our paper relies on full information methods and estimate a full-fledged DSGE model where house price fluctuations affect firms' and households' balance sheets. Contrary to the previous literature, we focus on house prices rather than stock returns. Empirically, house and stock prices are highly correlated (Figures 4.1-4.3) and swings in both kinds of assets have been highlighted as key factors behind business cycles.³ However, differently from most assets, real estate serves two important functions, which makes the whole economy vulnerable to house price movements. Houses are durable goods which provide services for households. As a result, a major share of households' wealth is held in this form. According to numerous empirical studies,⁴ house price fluctuations have a greater impact on aggregate spending than stock returns. Moreover, a large share of bank assets uses housing as collateral. Since bank lending is highly dependent on collateral values, there is a positive relation between credit and house prices (the bank credit channel). Moreover, house price inflation, but not stock price inflation, has a better predictive content for both inflation and output.⁵

From a methodological point of view, our paper is closely related to Lubik and Schorfheide (2007) who estimate a small-scale general equilibrium model of a small open economy and compare different Taylor rules using Bayesian methods. They use posterior odds tests to investigate whether central banks respond to exchange rates in the case of Australia, New Zealand, Canada and the U.K. We perform the same kind of exercise in a medium-scale model but instead test for the response to house prices. Using full information methods, we can deal with the endogeneity

³ Once we detrend the data, these two series do not exhibit a positive correlation in the U.S. and the U.K. Since we use detrended data in our analysis, this excludes the possibility that our results capture the response of central banks to stock prices rather than to house prices.

⁴ See e.g. Carroll, Otsuka, and Slacalek (2006) among others.

⁵ See e.g. Stock and Watson (2003) and Filardo (2000).

problem and use the cross equation restrictions implied by the model to identify the parameters of interests. Moreover, we can infer the business cycle implications of a central bank that reacts to house price inflation.

A growing number of papers structurally estimate DSGE models. However, most of these studies are limited to the U.S. and the Euro area and, except for Iacoviello (2005) and Iacoviello and Neri (2007), none of them introduces a housing sector. As for applications to the U.S. economy and the Euro area, Smets and Wouters (2003, 2007), Adolfson, Laséen, Lindé, and Villani (2007a), Queijo von Heideken (2007a) and Iacoviello and Neri (2007), all use Bayesian methods to estimate medium-scale DSGE models. In the case of the U.K., DiCecio and Nelson (2007) estimate the model of Christiano, Eichenbaum, and Evans (2005) using a minimum-distance estimation procedure. For Japan, Iiboshi, Nishiyama, and Watanabe (2007) and Sugo and Ueda (2007) estimate medium-scale DSGE models using Bayesian methods.

On theoretical grounds, we follow rather closely Iacoviello (2005) who develops a monetary business cycle model with nominal loans and collateral constraints tied to housing values.⁶ The mechanism in our model features a dynamic interaction between credit limits and asset prices as in Kiyotaki and Moore (1997). In the model, changes in house prices affect the borrowing capacity of borrowers, while movements in consumer prices influence the real value of their nominal debt. Another related paper is Iacoviello and Neri (2007), which develops a model with collateral constraints and estimate it using Bayesian methods for the U.S. As opposed to our model, however, theirs does not include an entrepreneurial sector but instead includes housing investment in a two-sector economy. In their paper, the main purpose is to identify the determinants of house price movements and measure the spillovers from the housing market to the rest of the economy. In our paper, we are mostly interested in empirically testing whether central banks have reacted to house price movements in the past.

The paper is organized as follows. Section 2 describes the model. In Section 3, we present the data, the estimation methodology and the results. We check the robustness of our results in Section 4. Section 5 concludes.

⁶ Iacoviello estimates the key structural parameters by minimizing the distance between the impulse responses implied by the model and those generated by an unrestricted vector autoregression in the U.S.

2 The model

The model we estimate follows the work of Iacoviello (2005) who incorporates nominal loans and collateral constraints into a monetary business cycle model. The presence of nominal debt contracts and a borrowing constraint are at the heart of debt deflation and collateral effects which enrich the transmission mechanism of the model. Changes in house prices affect the capacity to borrow (collateral effect), while movements in consumer prices influence the real value of their debt (debt deflation). For instance, after a positive demand shock, the resulting increase in house prices raises the capacity to borrow, thereby further stimulating demand. In the same way, the resulting increase in consumer prices transfers wealth from lenders to borrowers. Since borrowers have a higher propensity to consume in the model, this raises aggregate demand yet further.

The economy is populated by three kinds of agents: entrepreneurs and patient and impatient households. These agents discount future utility at different rates and borrow using housing as collateral. Entrepreneurs consume a nondurable final good and produce an intermediate good combining capital, real estate and the labor of both kinds of households. Households consume a nondurable good, own real estate and work for the entrepreneurs in a monopolistically competitive labor market. Real estate is in fixed supply. A retail sector is introduced to generate nominal rigidity. The central bank manages monetary policy using a Taylor-type interest rate rule. We enrich the dynamics of the model by introducing habit formation in consumption, sticky wages, price and wage indexation and seven structural shocks. In the following subsections, the model is described in more detail.

2.1 Patient and impatient households

There are two kinds of households, patient, denoted with prime (" ' "), and impatient, denoted with double prime (" " "). Each group has a continuum of agents indexed by $i \in (0, 1)$. Impatient households discount the future more heavily than patient ones ($\beta'' < \beta'$). Both groups maximize a lifetime utility function given by:

$$\text{Max} E_0 \sum_{t=0}^{\infty} z_t (\beta')^t \left(\ln (c'_{i,t} - \zeta C'_{t-1}) + j_t \ln h'_{i,t} - \frac{(l'_{i,t})^\eta}{\eta} \right),$$

$$\text{Max} E_0 \sum_{t=0}^{\infty} z_t (\beta'')^t \left(\ln (c''_{i,t} - \zeta C''_{t-1}) + j_t \ln h''_{i,t} - \frac{(l''_{i,t})^\eta}{\eta} \right),$$

where c is consumption, h housing, l hours of work and ζ the degree of habit formation with respect to aggregate consumption of each group (C).⁷ The variables z and j represent shocks to aggregate demand and housing demand, which both follow AR(1) processes.

Households are price setters in the labor market. Wages can only be optimally readjusted with probability $1 - \theta_w$. Wages of households that cannot re-optimize are fully indexed to past inflation. Workers set nominal wages maximizing their objective function subject to the intertemporal budget constraint and the following labor demand equations:

$$l'_{i,t} = \left(\frac{w'_{i,t}}{w'_t} \right)^{\frac{\lambda_t}{1-\lambda_t}} L'_t,$$

$$l''_{i,t} = \left(\frac{w''_{i,t}}{w''_t} \right)^{\frac{\lambda_t}{1-\lambda_t}} L''_t,$$

where λ is a time varying wage markup and w are nominal wages. Following Christiano, Eichenbaum, and Evans (2005), we assume that households buy securities with payoffs contingent on whether they can reoptimize their wages. This ensures that, in equilibrium, households within each group are homogenous in consumption and asset holdings.

Households face the following budget constraints:

$$c'_{i,t} + q_t \Delta h'_{i,t} + \frac{R_{t-1}}{\pi_t} b'_{i,t-1} = b'_{i,t} + \frac{w'_{i,t}}{P_t} l'_{i,t} + F_{i,t} + T'_{i,t},$$

$$c''_{i,t} + q_t \Delta h''_{i,t} + \frac{R_{t-1}}{\pi_t} b''_{i,t-1} = b''_{i,t} + \frac{w''_{i,t}}{P_t} l''_{i,t} + T''_{i,t},$$

where q denotes real house prices, b real debt,⁸ F lump-sum transfers received by patient households from retailers and T net cash inflows from participating in

⁷ Real balances do not enter households' utility function since we assume a cashless limiting economy as in Woodford (2003).

⁸ We assume that households can save only in one period bonds. This implies flexible interest rates on loans. Even though this is a reasonable assumption for the U.K., where mortgage loans are primarily extended on a floating rate basis, it is not the case in the U.S. where fixed rate contracts are more widely used. In Japan, interest rates are mainly tied to market rates or fixed between one and five years.

state-contingent security markets.⁹

Impatient households can borrow up to a limit defined by the following borrowing constraint:

$$b''_{i,t} \leq m'' E_t \left(q_{t+1} h''_{i,t} \frac{\pi_{t+1}}{R_t} \right).$$

Given that $\beta'' < \beta'$, this constraint holds with equality in steady state.¹⁰ As in Iacoviello (2005), we assume that uncertainty is sufficiently small to make the borrowing constraint always bind in the loglinearized model. It is straightforward to see that movements in house prices affect the borrowing capacity of impatient households through a collateral effect, while movements in consumer prices influence the real cost of their debt.

The first-order conditions for the households' problems are standard and their loglinearized versions are reported in Appendix 4.A.

2.2 Entrepreneurs and retailers

Entrepreneurs combine labor (L), capital (K) and real estate (h) to produce an intermediate good. We follow Iacoviello and Neri (2007) and assume that the types of labor supplied by the two kinds of households are not perfect substitutes. This simplifying assumption allows us to analytically compute the steady state of the model and disregard the complex interaction between borrowing constraints and labor supply decisions that would otherwise arise.

Entrepreneurs are risk adverse and maximize their discounted utility:

$$\text{Max} E_0 \sum_{t=0}^{\infty} \gamma^t \log c_t,$$

subject to a Cobb-Douglas production function, the flow of funds and borrowing constraints:

$$Y_t = a_t K_{t-1}^\mu h_{t-1}^\nu L_t'^{\alpha(1-\mu-\nu)} L_t''^{(1-\alpha)(1-\mu-\nu)},$$

$$\frac{Y_t}{X_t} + b_t = c_t + q_t \Delta h_t + \frac{R_{t-1}}{\pi_{t-1}} b_{t-1} + \frac{w'_t}{P_t} L_t' + \frac{w''_t}{P_t} L_t'' + \tilde{I}_t,$$

⁹ As described in the next subsection, we assume monopolistic competition in the retail sector. The resulting profits are rebated lump-sum to patient households (F).

¹⁰ In steady state, $\beta' - \beta'' = (1 - \zeta) c'' \chi''$, where χ'' is the multiplier associated with the borrowing constraint. Since we assume $\beta' - \beta'' > 0$, χ'' must be greater than zero in steady state which implies that the borrowing constraint holds with equality.

$$\begin{aligned}
K_t &= (1 - \delta) K_{t-1} + s_t \tilde{I}_t - \xi_{Kt}, \\
\tilde{I}_t &= \frac{I_t + \xi_{Kt}}{s_t}, \\
\xi_{K,t} &= \psi \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 \frac{K_{t-1}}{2\delta}, \\
b_t &\leq m E_t \left(q_{t+1} h_t \frac{\pi_{t+1}}{R_t} \right),
\end{aligned}$$

where:

$$\begin{aligned}
L'_t &= \left[\int_0^1 (l'_{i,t})^{\frac{1}{\lambda_t}} di \right]^{\lambda_t}, \\
L''_t &= \left[\int_0^1 (l''_{i,t})^{\frac{1}{\lambda_t}} di \right]^{\lambda_t},
\end{aligned}$$

the variable a represents an AR(1) technology shock, X denotes the markup of final over intermediate good ($X \equiv \frac{P}{P^w}$), ξ_K represents adjustment costs for capital installation,¹¹ and s is an investment-specific technological shock which follows an AR(1) process. Since by assumption $\gamma < \beta'$, the borrowing constraint holds with equality in steady state.¹² As in the case of impatient households, we assume the constraint to always be binding, also outside of the steady state.

Nominal rigidities are introduced by assuming that the intermediate good is transformed into a composite final good by a continuum of retailers indexed by n . Each retailer buys the intermediate good Y_t from the entrepreneurs at a price P_t^w and transforms it without costs into differentiated goods $Y_t(n)$ which are sold at a price $P_t(n)$. The differentiated goods are then aggregated into a final good Y^f according to a Dixit-Stiglitz aggregator:

$$Y_t^f = \left[\int_0^1 Y_t(n)^{\frac{1}{u_t}} dn \right]^{u_t},$$

¹¹ We also tried a different specification of the model with adjustment costs in the real estate sector. However, preliminary estimations of the model show that these costs do not play an important role in the dynamic of housing investments. These results are in line with Iacoviello (2005) and Iacoviello and Neri (2007).

¹² As in the case of impatient households, in steady state $\beta' - \gamma = c\chi$, where χ is the multiplier associated with the borrowing constraint. This implies that in steady state the borrowing constraint holds with equality.

where u is a time varying gross markup. The retail sector is monopolistically competitive and prices are sticky. With probability $1 - \theta$, the price of an individual firm can be optimally adjusted and the prices that are not re-optimized are fully indexed to past inflation. The loglinearized first-order conditions for entrepreneurs and retailers are reported in Appendix 4.A.

2.3 Monetary policy

Monetary policy is conducted according to a Taylor-type rule:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p E_t \hat{\pi}_{t+1} + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t] + \hat{m}_t,$$

where variables with a circumflex (" ^ ") represent log-deviations from the steady state and \hat{m} is an *iid* shock which captures a non-systematic component in the policy rule. In the sensitivity analysis, we try different specifications of the rule. As already described, the main purpose of the paper is to establish whether house prices do play a separate role in monetary policy.

2.4 Market equilibrium

Market equilibrium implies that all the optimality conditions corresponding to the above maximization problems are satisfied. In addition, real estate, goods and loan markets clear:

$$\begin{aligned} H &= h_t + h'_t + h''_t \\ Y_t &= C_t + C'_t + C''_t + \frac{I_t}{s_t} + \frac{\varepsilon_{Kt}}{s_t} \\ b_t + b'_t + b''_t &= 0. \end{aligned}$$

2.5 Shock structure

There are seven structural shocks in the economy: productivity, investment, housing demand, preferences, monetary, price markup and wage markup. The first four shocks follow stochastic processes given by:

$$v_t = (1 - \rho_v) v + \rho_v v_{t-1} + \varepsilon_{v,t},$$

while the two markup shocks and the monetary shock are *iid*:

$$v_t = v + \varepsilon_{v,t}.$$

The variances of the ε_v shocks are denoted by σ_v^2 .

The model is loglinearized around its deterministic steady state and solved numerically using the methods described in Sims (2002). In Appendix 4.A, we report the whole system of equations.

3 Estimation results

We estimate the model for the U.S., U.K. and Japan using Bayesian methods. Combining prior distributions with the likelihood function of the data, we obtain the posterior kernel which is proportional to the posterior density. Since the posterior distribution is unknown, we use Markov Chain Monte Carlo (MCMC) simulation methods to conduct inference about the structural parameters.¹³

The data used for the estimation corresponds to the seven variables in the model: real consumption, real investment, hours worked, real wages, real house prices, inflation and nominal interest rates.¹⁴ A detailed description of the data can be found in Appendix 4.B. For the U.S. and the U.K., we use quarterly data between 1983:Q1-2006:Q4. We choose this period since we can treat the period after 1983 as a single regime in both countries.¹⁵ For Japan, we use data between 1970:Q1-1995:Q4 since after 1995, the nominal interest rate has been close to its zero lower bound. All series were detrended using a linear trend and seasonally adjusted prior to estimation.¹⁶

¹³ To check convergence, we run five different chains with a total of 100,000 draws each. We initialized the MCMC procedure using importance resampling. Convergence was monitored calculating the potential scale reduction as described in Gelman, Carlin, Stern, and Rubin (2004) and plotting each chain.

¹⁴ For house prices, we use data on residential house prices. Since housing is also used by entrepreneurs in the model, an aggregated index computed of both residential and commercial house prices could also be used. However, using residential house prices is a good approximation since this series is highly correlated with commercial house prices (considering detrended data).

¹⁵ In the case of the U.K., Queijo von Heideken (2007b) shows that there is some evidence of a regime switch after 1997, when the Bank of England was officially granted operational independence. However, we follow the literature estimating DSGE models and use data over a long sample where a constant-parameter policy reaction function may be a good approximation. DiCecio and Nelson (2007) use approximately the same period and argue that the data after 1979, when the Thatcher government first took office, can be considered as one regime.

¹⁶ We detrend the series of hours worked in Japan using a kinked linear trend to take into account

3.1 Prior distributions

The model has a total of 32 free parameters. Nine of these are calibrated, because they cannot be identified from the detrended data.¹⁷ The discount factors β' , β'' and γ are set at 0.9925, 0.97 and 0.98, respectively.¹⁸ The choice of the discount factor for patient households, β' , implies that the annual real interest rate in steady state is three percent. The steady state rate of depreciation of capital, δ , is set equal to 0.03, which corresponds to an annual rate of depreciation of twelve percent. The steady state price and wage markups are calibrated at twenty percent, while the coefficients in the production function μ and ν are set to 0.35 and 0.035. Last, we fix the average housing weight in the utility function, j , to calibrate steady state ratios of commercial and residential real estate to annual output around 70% and 145%, in consistency with the data.¹⁹

The priors for the remaining 23 parameters are set equal for the three countries since, in all these cases, we have relatively loose priors. We report the priors in Table 4.1. All shocks have an inverse gamma distribution with mean 0.01 and standard deviation 0.2. For the autoregressive coefficients of the shocks, we select a beta distribution with mean 0.85 and standard deviation 0.10.

For the behavioral parameters, we choose priors in line with results in the existing literature. The habit persistence parameter ζ is assumed to be beta distributed with mean 0.50 and standard deviation 0.20. We select a dispersed prior for this parameter since our posterior mean was lower than in other papers. The prior for the elasticity of labor supply η is normally distributed with mean 2 and standard error 0.75.

The Calvo parameters θ and θ_w , the probability of not adjusting prices and wages, have a beta prior with mean 0.70 and standard deviation 0.15. These priors imply that, on average, prices and wages are adjusted every ten months.

There is a lot of uncertainty around the parameter ψ governing the adjustment

the effect of the *jitán*, a decrease in the number of statutory workdays per week which took place between 1988 and 1993.

¹⁷ We use the same calibration for the three countries since the parameters we chose are included in the range of values usually used in country-specific studies.

¹⁸ These are the same values as those chosen in Iacoviello and Neri (2007) which guarantee that the borrowing constraints bind.

¹⁹ This is in line with data from the Flow of Funds accounts both for the U.S. and the U.K. However, these ratios will also depend on the estimated loan-to-value ratios (m, m'').

costs in capital. Bernanke, Gertler, and Gilchrist (1999) set this parameter equal to 0.25, while King and Wolman (1996) use a value of 2 based on estimations of Chirinko (1993). We choose a gamma distribution with mean 2 and standard error 1.

We assume "loan-to-value" ratios m and m'' to be beta distributed with mean 0.80 and standard deviation 0.05. Tsatsaronis and Zhu (2004) show that the maximum "loan-to-value" ratio for the U.S. and Japan is around 80% and somewhat higher for the U.K. Moreover, Iacoviello (2005) estimates these parameters to be 0.89 and 0.55 using U.S. data and minimizing the distance between the model and data impulse responses.²⁰

The labor income share of the unconstrained agents, α , is beta distributed with mean 0.64 and standard deviation 0.10. This is the value estimated in Iacoviello (2005) and consistent with other studies.

For the interest rate rule, we assume an autoregressive parameter ρ , beta distributed with mean 0.70 and standard deviation 0.10. The prior for the response coefficient of the interest rate to inflation Γ_π , is gamma distributed with mean 1.70 and standard deviation 0.20, while the response to output Γ_y , is gamma distributed with mean 0.125 and standard deviation 0.10. For the main parameter of interest, namely the response of the interest rate to house prices Γ_q , we postulate a gamma distribution with mean 0.15 and standard deviation 0.10. In the robustness analysis, we estimate the model with a different prior for this parameter.

3.2 General estimation results and posterior distributions

3.2.1 Results for the U.S.

We start by reporting the results for the U.S. Table 4.1 shows the mean and 95% posterior probability intervals for the benchmark model and for the same model estimated with the restriction $\Gamma_q = 0$. In both cases, the nominal interest rate entails a standard smoothing component and the mean reactions to expected inflation and output are around 1.95 and 0.09, in line with other studies. In the model where the interest rate reacts to house prices, the posterior mean of Γ_q is 0.08. However, looking at the posterior estimates of Γ_q may be misleading since the results may be

²⁰ Iacoviello and Neri (2007) calibrate m'' to 0.85.

influenced by the choice of our prior. In the next subsection, we report posterior odds ratios which take this fact into account and penalize models with unneeded free parameters.

The estimation of the structural parameters is robust to both specifications of the monetary policy and, in general, consistent with the previous literature. However, the habit persistence parameter ζ is lower than in other studies. This result reflects the fact that the model is able to generate hump-shaped responses of consumption to supply shocks, even without habit persistence. For instance, as discussed later, after a negative price markup shock, the hike in inflation deflates the real value of the debt for borrowers, thereby diminishing the initial fall in their consumption.

The elasticity of labor supply has a mean larger than the prior and around 3. Price and wage stickiness are in line with the priors and previous studies. Prices adjust, on average, after seven quarters while wages adjust after 3 quarters. Adjustment costs are estimated to be around 0.8.

Constrained agents have a labor income share $(1 - \alpha)$ around 29%²¹ and, on average, they borrow up to 70% of their housing stock. Entrepreneurs, on the other hand, borrow on average up to 56% of their housing stock.²² This result is opposite to Iacoviello (2005) who estimates loan-to-value ratios for entrepreneurs higher than for households, suggesting that entrepreneurs' real state can be used more easily as collateral.²³

All shocks are very persistent, especially technology and housing preference shocks. It is important to mention that housing preference shocks are larger than the rest and extremely persistent. One might thus wonder if an AR(1) specification for this shock is not overly restrictive.²⁴

²¹ This result is in line with macro estimates of the fraction of disposable income that goes to rule-of-thumb consumers.

²² In interpreting this result, we should take into account that, as mentioned above, our house price data does not include commercial housing. This might distort our estimates of the loan-to-value ratio for entrepreneurs.

²³ Also the house price series used by Iacoviello (2005), i.e., the Freddie Mac's conventional mortgage home price index, does not include commercial housing.

²⁴ For instance, we could think that housing preference shocks follow an AR(2) process instead.

3.2.2 Results for the U.K.

Table 4.2 shows the posterior distribution for the case of the U.K. According to our estimates, the Bank of England has reacted less aggressively to output and expected inflation and more strongly to house price inflation than the Fed. The mean value of Γ_q is 0.12.

The estimates of the other structural parameters are robust to the choice of monetary policy rule and, in general, similar to those in the U.S. However, there are some exceptions. Prices and wages adjust more often in the U.K. and adjustment costs in capital are larger. Our results are in line with Nelson and Nikolov (2004), who also find that contract durations for prices in the U.K. are shorter than in the U.S. DiCecio and Nelson (2007) find absence of wage stickiness in the U.K.

Concerning the shocks affecting the economy, investment shocks are more persistent in the U.K., and technology, prices and housing preference shocks are also larger in this country. As in the case of the U.S., housing shocks are the largest and extremely persistent.

3.2.3 Results for Japan

The results for Japan are shown in Table 4.3. The main difference as compared to the U.S. and the U.K. is the estimated response of the interest rate to house prices movements. The mean value of Γ_q is 0.19, two times larger than in the case of the U.S.

Another difference is the flexibility of prices and wages. According to our estimation, prices and wages adjust every eleven and five months, respectively, similarly to the U.K., and more often than in the U.S. This is consistent with Iiboshi, Nishiyama, and Watanabe (2007) who estimate prices and wages to be more flexible in Japan than in the U.S. and Europe. Moreover, capital adjustment costs are much larger than in the two other countries. Finally, the size of shocks is, in general, much larger in Japan, especially housing and markup shocks. Specifically, a one standard deviation shock to housing preferences in Japan moves house prices 2%.

3.3 Model comparison

To investigate whether the Fed, the Bank of England and the Bank of Japan responded to house price inflation over the sample periods, we calculate the log marginal data density for the two model specifications when $\Gamma_q = 0$ and $\Gamma_q > 0$, and compute posterior odds ratios. As mentioned before, posterior odds ratios penalize models with unneeded free parameters.

Table 4.4 reports the log marginal data density and posterior odd ratios for the three countries. Two results emerge from this table. First, the Bank of Japan and the Bank of England did react to house price inflation in the sample periods. The marginal data densities are larger when $\Gamma_q > 0$ and the posterior odds ratios of the hypothesis $\Gamma_q = 0$ against $\Gamma_q > 0$ are 0.02 and 0.006 respectively, indicating strong evidence in favor of the unrestricted model.²⁵

Second, there is at best very slightly evidence that the Fed did not directly respond to house price inflation in the last 23 years. The fact that the posterior for Γ_q in the unrestricted model is different from zero is related to the choice of our prior. Once we take this into account, the marginal data density prefers the restricted model.

3.4 Impulse response functions

In this subsection, we compare the reaction of some key variables to different shocks under the two monetary rules: $\Gamma_q = 0$ and $\Gamma_q > 0$. These results are shown in Figure 4.4 through Figure 4.15.²⁶

After a tightening of monetary policy (Figures 4.4, 4.8 and 4.12), aggregate demand, house prices and inflation fall. As mention in Section 2, in our model, the transmission mechanism of monetary policy is enriched by two additional channels compared to a standard new Keynesian DSGE: debt deflation and collateral effect. This propagation mechanism is qualitatively similar for the three countries and is not affected by the inclusion of house prices in the monetary policy rule. However,

²⁵ In the case of Japan, we also estimate the model using data between 1970:Q1 and 1990:Q4, before the housing market crash. The posterior mean of Γ_q is 0.10, somewhat lower than before and the model comparison analysis is inconclusive. From this result, one might infer that the response to house price inflation of the Bank of Japan has been stronger after the crash. However, a detailed investigation of this kind is beyond the purpose of this paper.

²⁶ Responses are presented in percentage points. The shocks are set to one standard deviation.

the impact response to monetary policy of inflation is larger in Japan, despite the fact that the estimated magnitude of the shock is similar to the one in the U.K. This result is not surprising given that, according to our estimation results, Japan has a higher degree of wage flexibility which causes a larger decrease in marginal costs on impact.

Housing preference shocks are equivalent to house price shocks, since the supply of housing is fixed in the model. A positive house price shock (Figures 4.5, 4.9 and 4.13) increases the spending capacity of borrowers, via the collateral effect described above, thus boosting demand. This has a positive impact on consumer prices which reinforces the initial effect through a debt deflation mechanism. As inflation goes up, the central bank raises the nominal interest rate, thereby dampening the initial increase in inflation and output. The increase in the real interest rate is larger when monetary policy reacts to house prices. In Japan, where the response of the monetary authority to house prices is stronger, the larger increase in interest rates when $\Gamma_q > 0$, counterbalances the debt deflation and collateral effects for the household sector. This mechanism causes almost a one percent fall in consumption for impatient households. In this case, a substitution effect²⁷ between housing and consumption dominates, causing a negative response of consumption to house prices. It is important to stress that after a housing shock, the three countries show a smaller response of output and inflation in the model where the central bank responds to house prices. To see if this has implications for output and inflation volatility, in Section 3.6 we study the business cycle implications of reacting to house price inflation.

In the case of supply shocks, collateral and debt deflation effects work in opposite directions. For instance, the fall in asset prices after a price markup shock (Figures 4.6, 4.10 and 4.14) cuts down the borrowing capacity of borrowers. On the other hand, the increase in inflation transfers wealth from lenders to borrowers. It turns out that the first effect dominates and total spending decreases. Interestingly, for the three countries, the propagation mechanism after a markup shock is not affected by a central bank that responds to house prices.

The same happens in the case of technology shocks (Figures 4.7, 4.11 and 4.15).

²⁷ A housing preference shock changes the marginal rate of substitution between consumption and housing.

A positive shock to productivity raises house prices, thus increasing the spending capacity of borrowers. The fall in consumer prices, on the other hand, transfers wealth towards lenders, but borrowers still choose to raise their consumption.

3.5 Variance decomposition

To analyze the importance of the different shocks in the data, we perform variance decomposition analysis. In Tables 4.5, 4.6 and 4.7, we report the variance decomposition 1, 4 and 20 periods ahead for the U.S., the U.K. and Japan. For the U.S., we limit ourselves to the case $\Gamma_q = 0$, since the evidence from the model comparison analysis prefers this model. For the U.K. and Japan, we instead report the results for the model with $\Gamma_q > 0$ since this is preferred by the data.

Tables 4.5 reports the variance decomposition analysis for the U.S. House price movements are mostly driven by house preference shocks at all horizons, while technology shocks explain about 22% of house price fluctuations in the long run. Monetary policy shocks explain 11% of the variation in house prices in the short run, but this effect disappears at longer horizons. In the medium and long run, output, consumption and inflation variations are mainly explained by two supply shocks: technology and price markups. Together, these shocks account for about 83% of output variation and 89% of inflation variation after five years. However, at short horizons, monetary and preferences shocks also play a role in explaining consumption and output fluctuations. Investment shocks mainly drive fluctuations in the investment series at all horizons.

The results for the U.K. are shown in Table 4.6. House price movements are mostly explained by housing preferences shocks. In contrast to the U.S., technology and monetary policy shocks play a much smaller role for house price fluctuations. As in the U.S., supply shocks explain most of the variations of output, consumption and inflation in the medium/long run while monetary shocks play a role only in the short term. However, in the U.K., technology shocks play a smaller role than in the U.S. for the volatility of most of the variables. For example, technology shocks explain only 6% of inflation variation in the long run, while they drive almost 40% in the U.S.

Table 4.7 shows the results for Japan. The first thing to notice is that technology shocks have a much larger effect on house prices than in the U.S. and the U.K.:

technology shocks explain one third of the variation in house prices in the long run. Second, and given the estimated stronger reaction to house price inflation of the Bank of Japan, housing shocks are more important for explaining interest rate movements. In the long run, housing shocks explain 9% of the variability in the interest rate, while in the U.S. they account for 2%. In Japan technology and price markup shocks are also the main source of variations for output, consumption and inflation. Technology shocks are even more important in capturing the fluctuations of output in the long run and explain up to 78% of GDP variation after 20 quarters.

3.6 Business cycle implications of reacting to house prices

In order to understand the business cycle implications of a central bank responding to house prices, we perform a counterfactual analysis and simulate the economy when $\Gamma_q > 0$ and $\Gamma_q = 0$, keeping all the other parameters fixed. We simulate the model for the three countries using a sample of 1,000 draws of the model where the central bank reacts to house prices ($\Gamma_q > 0$), and generating 100 simulations for 75 periods. Table 4.8 shows that for given parameters, whether a central bank reacts to house price inflation or not has no significant impact on inflation volatility, while it reduces the variability of output in the three countries under study. However, these results do not necessarily have normative implications, for at least two reasons. First, in our counterfactual experiment, we keep the other parameters in the Taylor rule fixed. It may be the case that different values of the response of the monetary authority to expected inflation or output have the same effect on output and inflation volatility as a positive coefficient on house price inflation. Second, just studying output and inflation volatility could be misleading. A more accurate approach would be to derive a microfounded loss function for the monetary authority. However, this is left to future research.

4 Robustness

In order to check the robustness of our results, we reestimate the model in four ways, using three alternative interest rate rules, and changing the prior for Γ_q .²⁸ Tables

²⁸ In results not reported here, we also estimate the model using expected inflation one year ahead, $E_t\pi_{t+4}$, in the Taylor rule. The results in this case are analogous to those using $E_t\pi_{t+1}$.

4.9-4.11 show the posterior distribution of the monetary policy parameters under the alternative models for the three countries.

Lower prior

First, we reestimate the model using a lower prior mean for Γ_q . We choose a gamma distribution with mean 0.10 and standard deviation 0.10. This works as a good robustness check since the mode of the prior is at zero, which shifts the results in favor of finding a lower response to house price movements. However, the results are the same as before with the only difference being a slightly movement to the left of the posterior distribution of Γ_q . This is consistent with our findings that the Fed did not react to house price movements in the sample. In the case of the U.K., the evidence in favor of the unrestricted model is not as strong as before since the log marginal data density for the unrestricted model is lower than before. For Japan, there is still clear evidence that the Bank of Japan reacted to house prices inflation.

Expected inflation and house price levels

Second, we reestimate the model using the following modified Taylor rule:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p E_t \hat{\pi}_{t+1} + \Gamma_y \hat{y}_t + \Gamma_{qq} \hat{q}_t] + \hat{m}_t. \quad (\text{Rule 2})$$

This specification assumes that central banks react to house price levels rather than house price inflation. We set a prior distribution for Γ_{qq} equal to that for Γ_q . Under Rule 2, the estimation of all parameters is robust to the monetary policy rule and similar to the benchmark model. For the three countries, the response of the interest rate to house price levels is close to zero and the posterior odds ratios prefer the model where $\Gamma_{qq} = 0$. The large decrease in the marginal likelihood indicates that none of the Fed, the Bank of England or the Bank of Japan have responded to house price levels.

Contemporaneous inflation and house price inflation

We next use an interest rate rule of the type:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p \hat{\pi}_t + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t] + \hat{m}_t, \quad (\text{Rule 3})$$

where the monetary authority reacts to contemporaneous, rather than expected, inflation. In this case, the posterior distribution of the structural parameters is

similar to that reported in Section 3 for the three countries. The only exception is the Calvo parameter for prices which is slightly lower in the U.K. and Japan, as compared to the benchmark case.

Looking at the policy parameters, the estimates of the interest rate smoothing parameter ρ , and the response to output are similar to the one in the benchmark model for the three countries. However, the estimated response to contemporaneous inflation is lower than the response to future inflation. The estimated response to house price inflation is similar to the benchmark case for the U.S. and the U.K., while it is much larger for Japan.

Posterior odds tests confirm our result that the Bank of Japan reacted to house price inflation, while the Fed did not. In the case of the U.K., the data slightly prefers the model with $\Gamma_q = 0$. However, the marginal data density is lower than in the benchmark model, confirming our result that the Bank of England reacted to both future inflation and house price movements.

House price levels and house price inflation

Last, we reestimate the model using the following interest rate rule:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p \hat{\pi}_t + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t + \Gamma_{qq} \hat{q}_t] + \hat{\eta}_t. \quad (\text{Rule 4})$$

With this specification, we are testing whether central banks respond to a combination of house price levels as well as their movements. As before, we set a prior distribution for Γ_{qq} equal to the one for Γ_q . As in the case of Rule 2, the response of the interest rate to house price levels is very low. This translates into lower marginal data densities in the case when $\Gamma_{qq} > 0$, penalizing the unrestricted model. As a result, this model is rejected in the three countries.

The above results strengthen our conclusion that the Fed neither reacted to house prices nor house price inflation in the last decades. In Japan and the U.K., however, the central banks reacted to house price inflation when setting its monetary policy.

5 Conclusions

In this paper, we ask whether the Bank of England, the Bank of Japan or the Federal Reserve have reacted to changes in house prices. To deal with the endogeneity

problem that would arise estimating Taylor rules with asset prices in a univariate setting, we use full information methods. We specify a medium-scale DSGE model based on Iacoviello (2005), but enriched by a number of modifications to improve its empirical fit. In this model economy, business cycle fluctuations are amplified because credit constrained agents borrow using real estate as collateral. We estimate the model with Bayesian methods and employ posterior odds ratios tests to perform model comparison. Our main result is that house price movements did not play a separate role in the Fed reaction function over the sample period, while they did in the U.K. and Japan. This result is robust to different specifications of the estimated monetary policy rule. Remarkably, house prices display larger variation in the UK and Japan over the period considered. Moreover, according to Detken and Smets (2004), between 1970 and 2002, these two countries have mainly experienced "high cost" asset price booms, while, over the same sample period, asset price booms were not followed by a sharp drop in real GDP in the U.S.

Our results contribute to the scarce empirical literature on estimated DSGE models for the U.K. and Japan and help us determine the shocks behind business cycles in those countries. For these two countries, we estimate a lower degree of price and wage stickiness compared to the U.S. In all three countries, supply shocks play a major role in explaining business cycle fluctuations.

Our structural investigation allows us to identify the business cycle implications of a central bank reacting to house prices. According to our results, such a central bank is able to better protect the economy from turbulences stemming from real estate markets.²⁹ However, it is important to stress that this is true only when house price movements are generated by house price shocks. In practice, it is difficult for a central bank to know with certainty which shock causes observed fluctuations in house prices. Moreover, according to the results of our counterfactual experiment, whether a central bank reacts to house price inflation or not has no significant impact on inflation volatility, while it reduces the variability of output in the three countries under study. However, as discussed at some length in Section 3, it would be misleading to draw normative conclusions from this result. Answering the question of whether a central bank should react to house prices is left to future research.

²⁹ One related question is to what extent house price inflation is driven by fundamental or non-fundamental changes. In our paper, all movements in house prices are caused by fundamental shocks.

Last, the model we estimate includes only one-period bonds. As a result, we might overestimate the response of the economy to monetary policy in a country like the U.S., where fixed rate mortgage loans are widely used. It would be interesting to study how a richer financial structure would affect our results.

Appendix

4.A Steady state and log-linearized model

4.A.1 Steady state

Assuming zero inflation in steady state, the steady state of the model is given by:

$$1 = \beta R$$

$$\frac{I}{Y} = \frac{\delta \mu \gamma}{X(1 - (1 - \delta)\gamma)}$$

$$\frac{C}{Y} = \frac{1}{X} \left(\mu + \nu - m \frac{\gamma \nu (1 - \beta')}{(1 - \gamma_e)} - \frac{\mu \gamma \delta}{1 - (1 - \delta)\gamma} \right)$$

$$\frac{C''}{Y} = \frac{1 - \gamma_h}{(1 - \beta') m'' j (1 - \zeta) + 1 - \gamma_h} s''$$

$$\frac{b}{Y} = m \beta' \frac{\nu \gamma}{(1 - \gamma_e)} \frac{1}{X}$$

$$\frac{b''}{Y} = \frac{\beta (1 - \zeta) j m''}{(1 - \beta') m'' (1 - \zeta) j + 1 - \beta'' - m'' (\beta' - \beta'')} s''$$

$$\frac{qh}{Y} = \frac{\nu \gamma}{(1 - \gamma_e)} \frac{1}{X}$$

$$\begin{aligned} \frac{qh'}{Y} &= (1 - \zeta) j m'' \left(\frac{j (1 - \zeta)}{(1 - \beta') m'' j (1 - \zeta) + 1 - \gamma_h} s'' \right) \\ &+ (1 - \zeta) j m \left(\frac{\nu \gamma}{(1 - \gamma_e)} \frac{1}{X} \right) + \frac{s' (1 - \zeta) j}{(1 - \beta')} \end{aligned}$$

$$\frac{qh''}{Y} = \frac{j (1 - \zeta)}{(1 - \beta') m'' j (1 - \zeta) + 1 - \gamma_h} s'',$$

where:

$$s' = \frac{\alpha (1 - \mu - \nu) + X - 1}{X}$$

$$s'' = \frac{(1 - \alpha) (1 - \mu - \nu)}{X}$$

$$\gamma_h = \beta'' + m'' (\beta' - \beta'')$$

$$\gamma_e = (1 - m)\gamma + m\beta'.$$

4.A.2 Log-linearized model

The model is loglinearized around its deterministic steady state where variables with a circumflex ($\hat{\cdot}$) represent log-deviations from the steady state. The first order conditions for patient and impatient households' choice of consumption, real state and wages are³⁰:

$$\hat{z}_t - \hat{c}'_t + \zeta \hat{c}'_{t-1} = E_t (\hat{r}_t - \hat{\pi}_{t+1} + \hat{z}_{t+1} - \hat{c}'_{t+1} + \zeta \hat{c}'_t)$$

$$\begin{aligned} \hat{q}_t = & \beta' E_t \hat{q}_{t+1} + (1 - \beta') \hat{j}_t + \iota \hat{h}_t + \iota'' \hat{h}_t'' + \frac{\hat{c}'_t - \zeta \hat{c}'_{t-1}}{(1 - \zeta)} \\ & - \beta' E_t \left(\frac{\hat{c}'_{t+1} - \zeta \hat{c}'_t}{(1 - \zeta)} \right) + \beta' E_t (\hat{z}_{t+1} - \hat{z}_t) \end{aligned}$$

$$\begin{aligned} \hat{w}_t^{r'} = & \frac{1}{1 + \beta'} \hat{w}_{t-1}^{r'} + \frac{\beta'}{1 + \beta'} E_t \hat{w}_{t+1}^{r'} - \hat{\pi}_t + \frac{\beta'}{1 + \beta'} E_t \hat{\pi}_{t+1} + \frac{1}{1 + \beta'} \hat{\pi}_{t-1} \\ & + \frac{1}{1 + \beta'} \frac{(1 - \theta_w \beta') (1 - \theta_w)}{\theta_w (1 - (\eta - 1) \frac{\lambda}{1 - \lambda})} \left[(1 - \zeta)^{-1} (\hat{c}'_t - \zeta \hat{c}'_{t-1}) + (\eta - 1) \hat{l}'_t - \hat{w}_t^{r'} \right] + \hat{\lambda}_t \end{aligned}$$

$$\begin{aligned} \hat{q}_t = & \gamma_h E_t \hat{q}_{t+1} + (1 - \gamma_h) (\hat{j}_t + \hat{z}_t - \hat{h}_t'') \\ & - (1 - m'' \beta') (\hat{z}_t - \omega E_t (\hat{z}_{t+1})) \\ & - m'' \beta' (\hat{r}_t - E_t \hat{\pi}_{t+1}) + (1 - m'' \beta') \left(\frac{\hat{c}''_t - \zeta \hat{c}''_{t-1}}{(1 - \zeta)} - \omega \frac{E_t (\hat{c}''_{t+1} - \zeta \hat{c}''_t)}{(1 - \zeta)} \right) \end{aligned}$$

$$\begin{aligned} \hat{w}_t^{r''} = & \frac{1}{1 + \beta''} \hat{w}_{t-1}^{r''} + \frac{\beta''}{1 + \beta''} E_t \hat{w}_{t+1}^{r''} - \hat{\pi}_t + \frac{\beta''}{1 + \beta''} E_t \hat{\pi}_{t+1} + \frac{1}{1 + \beta''} \hat{\pi}_{t-1} \\ & + \frac{1}{1 + \beta''} \frac{(1 - \theta_w \beta'') (1 - \theta_w)}{\theta_w (1 - (\eta - 1) \frac{\lambda}{1 - \lambda})} \left[(1 - \zeta)^{-1} (\hat{c}''_t - \zeta \hat{c}''_{t-1}) + (\eta - 1) \hat{l}''_t - \hat{w}_t^{r''} \right] \\ & + \frac{(1 - \theta_w \beta'') (1 + \beta')}{(1 - \theta_w \beta') (1 + \beta'')} \hat{\lambda}_t. \end{aligned}$$

³⁰ Here we express wages in real terms, \hat{w}_t^r .

The budget and borrowing constraints for impatient households are:

$$\frac{b''}{Y}\hat{b}_t'' + s''(\hat{y}_t - \hat{x}_t) = \frac{C''}{Y}\hat{c}_t'' + \frac{qh''}{Y}\Delta\hat{h}_t'' + \frac{Rb''}{Y}(\hat{b}_{t-1}'' - \hat{\pi}_t + \hat{r}_t)$$

$$\hat{b}_t'' = E_t(\hat{q}_{t+1} + \hat{h}_t'' + \hat{\pi}_{t+1} - \hat{r}_t).$$

The first order conditions for entrepreneurs' choice of investment, real state, and labor are:

$$\hat{i}_t - \hat{k}_{t-1} = \gamma E_t(\hat{i}_{t+1} - \hat{k}_t) + \frac{1 - (1 - \delta)\gamma}{\psi} E_t(\hat{y}_{t+1} - \hat{x}_{t+1} - \hat{k}_t)$$

$$+ \frac{\hat{c}_t - E_t\hat{c}_{t+1}}{\psi} + \frac{\hat{s}_t - (1 - \delta)\gamma E_t\hat{s}_{t+1}}{\psi} - \frac{\hat{z}_t - E_t\hat{z}_{t+1}}{\psi}$$

$$\hat{q}_t = \gamma_e E_t\hat{q}_{t+1} + (1 - \gamma_e) E_t(\hat{y}_{t+1} - \hat{x}_{t+1} - \hat{h}_t) - m\beta'(\hat{r}_t - \hat{\pi}_{t+1})$$

$$- (1 - m\beta') E_t(\hat{c}_{t+1} - \hat{c}_t - \hat{z}_{t+1} + \hat{z}_t)$$

$$\hat{l}_t = \hat{y}_t - \hat{x}_t - \hat{w}_t^{lr}$$

$$\hat{l}_t'' = \hat{y}_t - \hat{x}_t - \hat{w}_t^{lrr}.$$

The budget and borrowing constraints for entrepreneurs are:

$$(\hat{y}_t - \hat{x}_t)(1 - s' - s'') + \frac{b}{Y}\hat{b}_t = \frac{C}{Y}\hat{c}_t + \frac{qh}{Y}\Delta\hat{h}_t + \frac{Rb}{Y}(\hat{b}_{t-1} - \hat{\pi}_t + \hat{r}_{t-1}) + \frac{I}{Y}(\hat{i}_t - \hat{s}_t)$$

$$\hat{b}_t = E_t(\hat{q}_{t+1} + \hat{h}_t + \hat{\pi}_{t+1} - \hat{r}_t).$$

The production technology and capital accumulation are given by:

$$\hat{y}_t = \frac{1}{\mu + \nu}(\hat{a}_t + \mu\hat{k}_{t-1} + \nu\hat{h}_{t-1}) - \frac{(1 - \mu - \nu)}{\mu + \nu}\hat{x}_t - \frac{(1 - \mu - \nu)}{\mu + \nu}(\alpha\hat{w}_t^{lr} + (1 - \alpha)\hat{w}_t^{lrr})$$

$$\hat{k}_t = \delta\hat{i}_t + (1 - \delta)\hat{k}_{t-1}.$$

Retailers choose prices so that:

$$\hat{\pi}_t = \frac{1}{1 + \beta'}\hat{\pi}_{t-1} + \frac{\beta'}{1 + \beta'}\hat{\pi}_{t+1} - \frac{1}{1 + \beta'}\frac{(1 - \theta\beta')(1 - \theta)}{\theta}\hat{x}_t + \hat{u}_t.$$

Monetary policy is given by:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p E_t \hat{\pi}_{t+1} + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t] + \hat{m}_t.$$

The market clearing condition is:

$$\hat{y}_t = \frac{C}{Y} \hat{c}_t + \frac{C'}{Y} \hat{c}'_t + \frac{C''}{Y} \hat{c}''_t + \frac{I}{Y} \hat{i}_t.$$

The structural shocks are:

$$\hat{z}_t = \rho_z \hat{z}_{t-1} + \varepsilon_{zt}$$

$$\hat{s}_t = \rho_s \hat{s}_{t-1} + \varepsilon_{st}$$

$$\hat{j}_t = \rho_j \hat{j}_{t-1} + \varepsilon_{jt}$$

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{at},$$

where:

$$\iota = (1 - \beta') \frac{h}{h'}$$

$$\iota'' = (1 - \beta') \frac{h''}{h'}$$

$$\omega = \frac{(\beta'' - m'' \beta')}{1 - m'' \beta'}$$

4.B The data

The data used for the estimation corresponds to seven variables of the model: real consumption, real investment, hours worked, nominal interest rate, inflation, real wages and real housing prices. All series were detrended using a linear trend and seasonally adjusted previous to estimation. Inflation is calculated as the difference of the GDP deflator. Nominal wages and house prices are converted into real terms using the GDP deflator

4.B.1 US

For the U.S. we use data between 1983:Q1-2006:Q4. Data on real personal consumption expenditures (B002RA3), real gross private domestic investment (B006RA3)

and GDP implicit price deflator (B191RG3), was taken from the Bureau of Economic Analysis of the U.S. Department of Commerce. Average weekly hours (CES0500000005) and average hourly earnings (CES0500000006) of production workers in the private sector were obtained from the Bureau of Labor Statistics. For house prices, we use the price index of new one-family houses sold including the value of the lot from the U.S. Census Bureau. The nominal interest rate is the Federal Funds Rate.

4.B.2 UK

The data for the U.K. also covers the period 1983Q1-2006Q4. Data on households final consumption expenditure (ABJR), total gross fixed capital formation (NPQT), GDP at market prices deflator (YBGB), total actual weekly hours of work (YBUS) and wages and salaries (ROYJ HN) was taken from National Statistics U.K. House prices are the prices of all residential properties obtained from the Nationwide Building Society. For the nominal interest rate, we use the quarterly average of the official bank rate (IUQABEDR) of the Bank of England.

4.B.3 Japan

In the case of Japan, we use data between 1970:Q1-1995:Q4 since after 1995 the nominal interest rates have been close to its zero lower bound. Data on private consumption, private non-residential investment and GDP deflator was obtained from the Official Cabinet. Aggregate weekly hours of work (non-agricultural industries) was obtained from the Statistic Bureau, Ministry of Internal Affairs and Communications. For nominal wages, we use monthly earnings in the private sector from the OECD database. For house prices, we use residential house prices obtained from the BIS database. For the nominal interest rate, we use the call money rate from the IFS database.

4.C Tables and Figures

Table 4.1: U.S. Data

Parameter	Prior Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SE	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.2	0.01	0.04	0.09	0.01	0.04	0.09
θ	beta	0.7	0.15	0.83	0.86	0.89	0.83	0.86	0.89
θ_w	beta	0.7	0.15	0.60	0.70	0.81	0.60	0.70	0.82
ψ	gamma	2	1	0.66	0.77	0.87	0.66	0.78	0.88
m	beta	0.8	0.05	0.49	0.56	0.62	0.49	0.56	0.62
m''	beta	0.8	0.05	0.63	0.70	0.77	0.63	0.70	0.77
α	beta	0.64	0.1	0.57	0.71	0.83	0.59	0.72	0.84
η	normal	2	0.75	2.20	3.16	4.19	2.14	3.12	4.16
ρ	beta	0.7	0.1	0.61	0.67	0.73	0.61	0.67	0.73
Γ_p	gamma	1.7	0.2	1.69	1.94	2.22	1.70	1.96	2.25
Γ_y	gamma	0.125	0.1	0.06	0.09	0.12	0.06	0.09	0.12
Γ_q	gamma	0.15	0.1	-	-	-	0.02	0.08	0.16
ρ_a	beta	0.85	0.1	0.970	0.972	0.976	0.969	0.972	0.976
ρ_j	beta	0.85	0.1	0.954	0.979	0.995	0.948	0.975	0.994
ρ_z	beta	0.85	0.1	0.848	0.876	0.914	0.846	0.873	0.913
ρ_s	beta	0.85	0.1	0.811	0.845	0.879	0.811	0.846	0.882
σ_a	i-gamma	0.01	0.2	0.0046	0.0052	0.0059	0.0046	0.0052	0.0059
σ_u	i-gamma	0.01	0.2	0.0013	0.0015	0.0017	0.0013	0.0015	0.0017
σ_j	i-gamma	0.01	0.2	0.0226	0.0488	0.0853	0.0246	0.0543	0.0951
σ_m	i-gamma	0.01	0.2	0.0017	0.0020	0.0024	0.0017	0.0021	0.0025
σ_z	i-gamma	0.01	0.2	0.0073	0.0088	0.0107	0.0074	0.0089	0.0107
σ_s	i-gamma	0.01	0.2	0.0223	0.0264	0.0308	0.0224	0.0266	0.0312
σ_λ	i-gamma	0.01	0.2	0.0015	0.0017	0.0020	0.0015	0.0017	0.0020

Table 4.2: U.K. Data

Parameters	Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SE	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.2	0.01	0.06	0.14	0.01	0.06	0.14
θ	beta	0.7	0.15	0.75	0.79	0.84	0.71	0.77	0.81
θ_w	beta	0.7	0.15	0.42	0.51	0.61	0.41	0.50	0.60
ψ	gamma	2	1	1.03	1.35	1.72	1.05	1.38	1.76
m	beta	0.8	0.05	0.46	0.53	0.59	0.48	0.55	0.62
m''	beta	0.8	0.05	0.64	0.71	0.78	0.66	0.73	0.80
α	beta	0.64	0.1	0.50	0.67	0.82	0.54	0.70	0.84
η	normal	2	0.75	1.64	2.33	3.17	1.77	2.47	3.31
ρ	beta	0.7	0.1	0.63	0.69	0.75	0.65	0.71	0.76
Γ_p	gamma	1.7	0.2	1.40	1.58	1.81	1.46	1.67	1.93
Γ_y	gamma	0.125	0.1	0.002	0.02	0.03	0.002	0.01	0.03
Γ_q	gamma	0.15	0.1	-	-	-	0.06	0.12	0.18
ρ_a	beta	0.85	0.1	0.935	0.962	0.981	0.928	0.956	0.978
ρ_j	beta	0.85	0.1	0.986	0.994	0.999	0.980	0.991	0.998
ρ_z	beta	0.85	0.1	0.871	0.906	0.935	0.867	0.900	0.930
ρ_s	beta	0.85	0.1	0.905	0.951	0.989	0.913	0.958	0.992
σ_a	i-gamma	0.01	0.2	0.0074	0.0083	0.0094	0.0074	0.0084	0.0095
σ_u	i-gamma	0.01	0.2	0.0047	0.0054	0.0062	0.0049	0.0056	0.0065
σ_j	i-gamma	0.01	0.2	0.0413	0.0626	0.0948	0.0456	0.0758	0.1202
σ_m	i-gamma	0.01	0.2	0.0021	0.0025	0.0029	0.0020	0.0024	0.0028
σ_z	i-gamma	0.01	0.2	0.0115	0.0142	0.0176	0.0124	0.0153	0.0187
σ_s	i-gamma	0.01	0.2	0.0256	0.0314	0.038	0.0263	0.0321	0.0387
σ_λ	i-gamma	0.01	0.2	0.0042	0.0049	0.0057	0.0043	0.0049	0.0057

Table 4.3: Japanese Data

Parameters	Prior Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SE	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.2	0.01	0.02	0.05	0.01	0.02	0.06
θ	beta	0.7	0.15	0.67	0.71	0.76	0.68	0.73	0.78
θ_w	beta	0.7	0.15	0.26	0.35	0.46	0.29	0.40	0.53
Ψ	gamma	2	1	2.71	3.16	3.62	2.60	3.07	3.56
m	beta	0.8	0.05	0.57	0.63	0.68	0.57	0.63	0.69
m''	beta	0.8	0.05	0.68	0.73	0.78	0.66	0.72	0.78
α	beta	0.64	0.1	0.52	0.68	0.82	0.58	0.72	0.84
η	normal	2	0.75	2.00	2.88	3.84	1.88	2.76	3.75
ρ	beta	0.7	0.1	0.72	0.77	0.80	0.73	0.77	0.81
Γ_p	gamma	1.70	0.2	1.68	1.94	2.23	1.72	1.99	2.27
Γ_y	gamma	0.125	0.1	0.003	0.02	0.04	0.003	0.02	0.04
Γ_q	gamma	0.15	0.1	-	-	-	0.09	0.19	0.29
ρ_a	beta	0.85	0.1	0.941	0.964	0.985	0.942	0.966	0.989
ρ_j	beta	0.85	0.1	0.931	0.957	0.980	0.920	0.948	0.973
ρ_z	beta	0.85	0.1	0.812	0.843	0.871	0.811	0.845	0.883
ρ_s	beta	0.85	0.1	0.909	0.937	0.964	0.908	0.938	0.967
σ_a	i-gamma	0.01	0.2	0.0110	0.0123	0.0139	0.0109	0.0123	0.0139
σ_u	i-gamma	0.01	0.2	0.0049	0.0057	0.0066	0.0048	0.0056	0.0064
σ_j	i-gamma	0.01	0.2	0.0946	0.1665	0.2510	0.1168	0.1924	0.2807
σ_m	i-gamma	0.01	0.2	0.0022	0.0026	0.0031	0.0022	0.0026	0.0031
σ_z	i-gamma	0.01	0.2	0.0101	0.0121	0.0145	0.0107	0.0127	0.0152
σ_s	i-gamma	0.01	0.2	0.0428	0.0507	0.0591	0.0413	0.049	0.0575
σ_λ	i-gamma	0.01	0.2	0.0093	0.0109	0.0128	0.0090	0.0105	0.0123

Table 4.4: Posterior Odds

Country	Log marginal data density		Posterior odds
	$\Gamma_q = 0$	$\Gamma_q > 0$	
U.S.	2452.6	2452.1	1.61
U.K.	2075.1	2078.9	0.02
Japan	2192.8	2200.3	0.006

Notes: The table reports posterior odds of the hypothesis $\Gamma_q = 0$ versus $\Gamma_q > 0$

Table 4.5: U.S. Variance decomposition

	ϵ_a	ϵ_u	ϵ_j	ϵ_m	ϵ_z	ϵ_{sw}	ϵ
1 period ahead							
Real House Price	0.12	0.11	0.56	0.11	0.08	0.00	0.01
	[0.08,0.16]	[0.08,0.16]	[0.48,0.65]	[0.08,0.15]	[0.05,0.15]	[0,0]	[0,0.01]
Output	0.19	0.37	0.04	0.29	0.07	0.02	0.01
	[0.12,0.27]	[0.29,0.45]	[0.03,0.07]	[0.23,0.36]	[0.05,0.12]	[0.01,0.03]	[0,0.01]
Inflation	0.02	0.97	0.00	0.00	0.00	0.00	0.00
	[0.01,0.04]	[0.94,0.98]	[0,0]	[0,0.01]	[0,0.01]	[0,0]	[0,0.01]
Nominal Interest Rate	0.00	0.30	0.00	0.69	0.01	0.00	0.00
	[0,0]	[0.22,0.39]	[0,0]	[0.6,0.77]	[0,0.01]	[0,0]	[0,0]
Agg. Consumption	0.21	0.33	0.00	0.27	0.17	0.00	0.01
	[0.14,0.29]	[0.25,0.4]	[0,0.01]	[0.22,0.34]	[0.12,0.24]	[0,0.01]	[0,0.01]
4 periods ahead							
Real House Price	0.17	0.11	0.57	0.04	0.10	0.00	0.01
	[0.12,0.23]	[0.07,0.16]	[0.47,0.65]	[0.03,0.05]	[0.06,0.175]	[0,0.01]	[0,0.01]
Output	0.32	0.42	0.03	0.14	0.04	0.02	0.01
	[0.22,0.43]	[0.33,0.52]	[0.02,0.05]	[0.11,0.18]	[0.03,0.07]	[0.01,0.03]	[0.01,0.02]
Inflation	0.14	0.80	0.00	0.01	0.02	0.00	0.01
	[0.09,0.21]	[0.72,0.87]	[0,0.01]	[0.01,0.03]	[0.01,0.04]	[0,0]	[0.01,0.02]
Nominal Interest Rate	0.05	0.55	0.01	0.33	0.04	0.00	0.01
	[0.03,0.08]	[0.46,0.63]	[0.01,0.02]	[0.26,0.415]	[0.03,0.07]	[0,0.01]	[0,0.01]
Agg. Consumption	0.35	0.38	0.00	0.13	0.11	0.01	0.01
	[0.25,0.46]	[0.3,0.47]	[0,0.01]	[0.1,0.17]	[0.08,0.16]	[0,0.01]	[0.01,0.02]
20 periods ahead							
Real House Price	0.22	0.03	0.64	0.01	0.06	0.02	0.00
	[0.15,0.34]	[0.02,0.06]	[0.46,0.74]	[0.01,0.02]	[0.03,0.14]	[0.01,0.03]	[0,0.01]
Output	0.62	0.21	0.02	0.06	0.02	0.05	0.01
	[0.51,0.705]	[0.15,0.3]	[0.01,0.03]	[0.04,0.08]	[0.01,0.03]	[0.04,0.09]	[0.01,0.03]
Inflation	0.39	0.50	0.00	0.01	0.05	0.02	0.02
	[0.27,0.53]	[0.365,0.62]	[0,0.01]	[0,0.03]	[0.03,0.09]	[0.01,0.04]	[0.01,0.03]
Nominal Interest Rate	0.30	0.34	0.02	0.17	0.12	0.01	0.02
	[0.2,0.43]	[0.25,0.43]	[0.01,0.03]	[0.13,0.24]	[0.07,0.18]	[0.01,0.03]	[0.01,0.03]
Agg. Consumption	0.65	0.18	0.00	0.05	0.05	0.05	0.01
	[0.56,0.73]	[0.12,0.25]	[0,0]	[0.04,0.07]	[0.03,0.07]	[0.03,0.08]	[0.01,0.03]

Notes: The table reports median and 95 percent probability intervals (in brackets).
Model $\Gamma_q = 0$

Table 4.6: U.K. Variance decomposition

	ϵ_a	ϵ_u	ϵ_j	ϵ_m	ϵ_z	ϵ_s	ϵ_w
1 period ahead							
Real House Price	0.07	0.13	0.71	0.04	0.05	0.00	0.00
	[0.04,0.1]	[0.09,0.19]	[0.62,0.77]	[0.03,0.05]	[0.02,0.09]	[0,0.01]	[0,0.01]
Output	0.18	0.55	0.03	0.14	0.08	0.00	0.01
	[0.12,0.26]	[0.45,0.64]	[0.01,0.06]	[0.11,0.19]	[0.05,0.12]	[0,0.01]	[0,0.01]
Inflation	0.01	0.96	0.00	0.01	0.01	0.00	0.01
	[0.01,0.02]	[0.93,0.98]	[0,0]	[0,0.02]	[0,0.02]	[0,0]	[0,0.01]
Nominal Interest Rate	0.00	0.61	0.08	0.30	0.00	0.00	0.00
	[0,0]	[0.51,0.69]	[0.03,0.16]	[0.23,0.39]	[0,0.01]	[0,0]	[0,0.01]
Agg. Consumption	0.18	0.51	0.00	0.14	0.13	0.01	0.01
	[0.12,0.25]	[0.41,0.6]	[0,0.02]	[0.1,0.18]	[0.09,0.2]	[0.01,0.03]	[0,0.01]
4 periods ahead							
Real House Price	0.08	0.09	0.73	0.01	0.07	0.00	0.01
	[0.06,0.12]	[0.06,0.14]	[0.65,0.79]	[0.01,0.02]	[0.04,0.12]	[0,0.01]	[0,0.01]
Output	0.30	0.54	0.03	0.07	0.04	0.00	0.02
	[0.21,0.42]	[0.42,0.65]	[0.01,0.05]	[0.05,0.09]	[0.02,0.06]	[0,0.01]	[0.01,0.03]
Inflation	0.05	0.82	0.01	0.04	0.06	0.00	0.02
	[0.025,0.08]	[0.735,0.89]	[0,0.02]	[0.02,0.07]	[0.04,0.1]	[0,0.01]	[0.01,0.03]
Nominal Interest Rate	0.04	0.67	0.07	0.12	0.06	0.01	0.02
	[0.02,0.07]	[0.56,0.77]	[0.03,0.14]	[0.09,0.16]	[0.03,0.11]	[0,0.01]	[0.01,0.03]
Agg. Consumption	0.31	0.51	0.00	0.065	0.07	0.02	0.02
	[0.21,0.42]	[0.39,0.62]	[0,0.02]	[0.05,0.09]	[0.05,0.11]	[0.01,0.04]	[0.01,0.03]
20 periods ahead							
Real House Price	0.06	0.02	0.85	0.00	0.05	0.01	0.00
	[0.04,0.11]	[0.01,0.04]	[0.77,0.9]	[0,0]	[0.02,0.09]	[0,0.02]	[0,0]
Output	0.52	0.31	0.03	0.04	0.02	0.06	0.01
	[0.38,0.65]	[0.21,0.44]	[0.02,0.05]	[0.03,0.06]	[0.02,0.04]	[0.03,0.1]	[0.01,0.02]
Inflation	0.06	0.76	0.01	0.04	0.10	0.00	0.02
	[0.03,0.11]	[0.69,0.83]	[0,0.03]	[0.02,0.06]	[0.06,0.14]	[0,0.01]	[0.01,0.03]
Nominal Interest Rate	0.09	0.47	0.09	0.08	0.21	0.01	0.02
	[0.05,0.15]	[0.36,0.59]	[0.05,0.15]	[0.06,0.11]	[0.14,0.3]	[0,0.04]	[0.01,0.03]
Agg. Consumption	0.52	0.29	0.00	0.04	0.04	0.09	0.01
	[0.38,0.65]	[0.19,0.41]	[0,0.01]	[0.02,0.05]	[0.03,0.06]	[0.04,0.175]	[0.01,0.02]

Notes: The table reports median and 95 percent probability intervals (in brackets) Model $\Gamma_q > 0$

Table 4.7: Japan Variance decomposition

	ϵ_a	ϵ_u	ϵ_j	ϵ_m	ϵ_z	ϵ_s	ϵ_w
1 period ahead							
Real House Price	0.20	0.12	0.54	0.06	0.04	0.02	0.02
	[0.15,0.26]	[0.08,0.17]	[0.46,0.61]	[0.04,0.09]	[0.02,0.07]	[0.01,0.02]	[0.01,0.03]
Output	0.41	0.31	0.02	0.15	0.07	0.00	0.02
	[0.3,0.52]	[0.23,0.4]	[0.01,0.05]	[0.11,0.2]	[0.04,0.11]	[0,0]	[0.01,0.04]
Inflation	0.03	0.88	0.00	0.03	0.02	0.00	0.04
	[0.02,0.06]	[0.82,0.93]	[0,0]	[0.01,0.05]	[0.01,0.03]	[0,0]	[0.02,0.06]
Nominal Interest Rate	0.00	0.49	0.08	0.40	0.00	0.00	0.02
	[0,0.01]	[0.395,0.58]	[0.03,0.17]	[0.32,0.48]	[0,0.01]	[0,0]	[0.01,0.03]
Agg. Consumption	0.38	0.29	0.00	0.14	0.09	0.06	0.02
	[0.28,0.48]	[0.22,0.37]	[0,0.015]	[0.11,0.19]	[0.06,0.14]	[0.03,0.09]	[0.01,0.04]
4 periods ahead							
Real House Price	0.27	0.08	0.51	0.02	0.07	0.02	0.03
	[0.21,0.34]	[0.05,0.13]	[0.42,0.595]	[0.01,0.03]	[0.04,0.11]	[0.01,0.03]	[0.02,0.04]
Output	0.59	0.25	0.02	0.06	0.03	0.00	0.04
	[0.46,0.7]	[0.17,0.36]	[0.01,0.03]	[0.04,0.09]	[0.02,0.05]	[0,0]	[0.02,0.07]
Inflation	0.10	0.67	0.00	0.09	0.06	0.00	0.07
	[0.06,0.16]	[0.58,0.75]	[0,0.01]	[0.05,0.13]	[0.04,0.1]	[0,0]	[0.05,0.1]
Nominal Interest Rate	0.07	0.51	0.07	0.17	0.08	0.00	0.09
	[0.03,0.12]	[0.415,0.61]	[0.04,0.13]	[0.13,0.21]	[0.04,0.13]	[0,0.01]	[0.06,0.12]
Agg. Consumption	0.55	0.23	0.00	0.06	0.04	0.07	0.04
	[0.43,0.65]	[0.15,0.33]	[0,0.01]	[0.04,0.08]	[0.02,0.06]	[0.04,0.11]	[0.02,0.06]
20 periods ahead							
Real House Price	0.35	0.03	0.51	0.01	0.05	0.04	0.01
	[0.22,0.49]	[0.02,0.06]	[0.35,0.65]	[0.01,0.01]	[0.02,0.09]	[0.02,0.06]	[0.01,0.02]
Output	0.78	0.11	0.01	0.03	0.01	0.03	0.02
	[0.67,0.87]	[0.06,0.18]	[0.01,0.02]	[0.02,0.04]	[0.01,0.02]	[0.02,0.05]	[0.01,0.04]
Inflation	0.11	0.66	0.01	0.08	0.06	0.00	0.06
	[0.06,0.2]	[0.565,0.74]	[0.01,0.02]	[0.05,0.13]	[0.04,0.1]	[0,0]	[0.04,0.09]
Nominal Interest Rate	0.17	0.37	0.09	0.12	0.15	0.00	0.08
	[0.09,0.27]	[0.28,0.47]	[0.05,0.14]	[0.09,0.16]	[0.1,0.23]	[0,0.01]	[0.05,0.12]
Agg. Consumption	0.71	0.10	0.00	0.02	0.02	0.12	0.02
	[0.59,0.8]	[0.055,0.16]	[0,0.01]	[0.01,0.04]	[0.01,0.03]	[0.07,0.21]	[0.01,0.04]

Notes: The table reports median and 95 percent probability intervals (in brackets)
 Model $\Gamma_q > 0$

Table 4.8: Counterfactual simulated standard deviation

	US		UK		JPN	
	$\Gamma_q > 0$	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q = 0$
π	0.39	0.39	0.97	0.97	0.95	0.93
Y	2.11	2.14	3.04	3.12	3.90	4.01

Notes: Posterior median for a sample of 100 simulations for 75 periods for 1,000 draws of the model with $\Gamma_q > 0$

Table 4.9: Posterior mean for U.S. data

	Expected Inflation				Contemporaneous Inflation		
	Benchmark		Lower prior	Rule 2	Rule 3		Rule 4
	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q > 0$	$\Gamma_{qq} > 0$	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q > 0$
	$\Gamma_{qq} = 0$				$\Gamma_{qq} = 0$		$\Gamma_{qq} > 0$
ρ	0.67	0.67	0.67	0.67	0.72	0.72	0.72
Γ_p	1.94	1.96	1.94	1.97	1.71	1.71	1.74
Γ_y	0.09	0.09	0.09	0.08	0.06	0.06	0.05
Γ_q	-	0.08	0.05	-	-	0.09	0.09
Γ_{qq}	-	-	-	0.008	-	-	0.005
Log marg data density	2452.6	2452.1	2451.0	2442.6	2434.2	2431.8	2424.9
Posterior odds	-	1.61	4.80	21315	-	11.23	11312

Notes: The table reports posterior odds of the hypothesis $\Gamma_q = \Gamma_{qq} = 0$ versus the unrestricted model

Table 4.10: Posterior mean for U.K. data

	Expected Inflation				Contemporaneous Inflation		
	Benchmark		Lower prior	Rule 2	Rule 3		Rule 4
	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q > 0$	$\Gamma_{qq} > 0$	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q > 0$
	$\Gamma_{qq} = 0$				$\Gamma_{qq} = 0$		$\Gamma_{qq} > 0$
ρ	0.69	0.71	0.70	0.70	0.75	0.76	0.76
Γ_p	1.58	1.67	1.67	1.61	1.44	1.47	1.51
Γ_y	0.02	0.01	0.01	0.01	0.02	0.02	0.02
Γ_q	-	0.12	0.11	-	-	0.09	0.09
Γ_{qq}	-	-	-	0.003	-	-	0.002
Log marg data density	2075.1	2078.9	2076.3	2064.4	2062.4	2061.4	2057.6
Posterior odds	-	0.022	0.31	44223	-	2.80	119.7

Notes: The table reports posterior odds of the hypothesis $\Gamma_q = \Gamma_{qq} = 0$ versus the unrestricted model

Table 4.11: Posterior mean for Japanese data

	Expected Inflation				Contemporaneous Inflation		
	Benchmark		Lower prior	Rule 2	Rule 3		Rule 4
	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q > 0$	$\Gamma_{qq} > 0$	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q > 0$
	$\Gamma_{qq} = 0$				$\Gamma_{qq} = 0$		$\Gamma_{qq} > 0$
ρ	0.77	0.77	0.77	0.77	0.80	0.81	0.81
Γ_p	1.94	1.99	1.92	1.97	1.56	1.62	1.64
Γ_y	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Γ_q	-	0.19	0.14	-	-	0.29	0.30
Γ_{qq}	-	-	-	0.01	-	-	0.01
Log marg data density	2192.8	2200.3	2197.0	2188.0	2170.5	2179.0	2169.0
Posterior odds	-	0.006	0.015	119.1	-	0.0002	4.7

Notes: The table reports posterior odds of the hypothesis $\Gamma_q = \Gamma_{qq} = 0$ versus the unrestricted mode

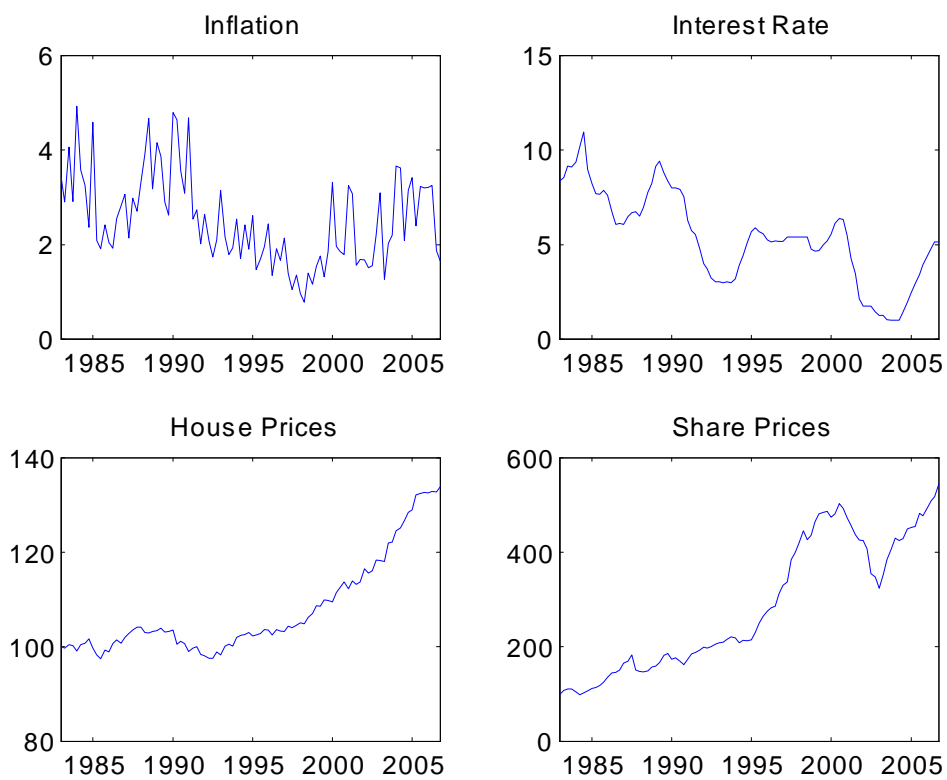


Figure 4.1: United States

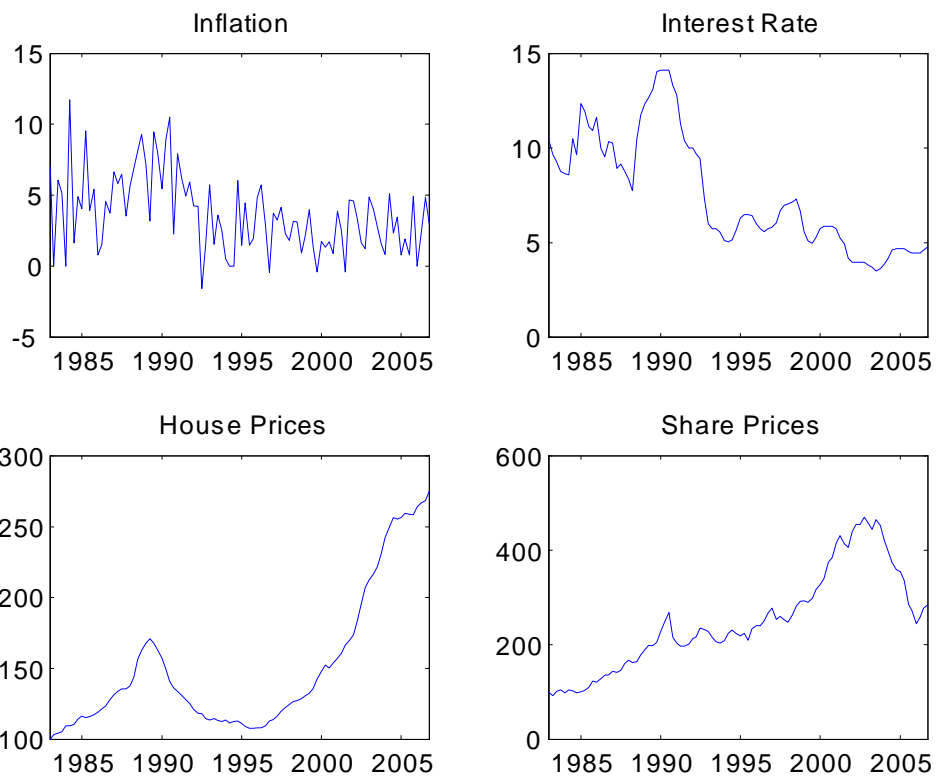


Figure 4.2: United Kingdom

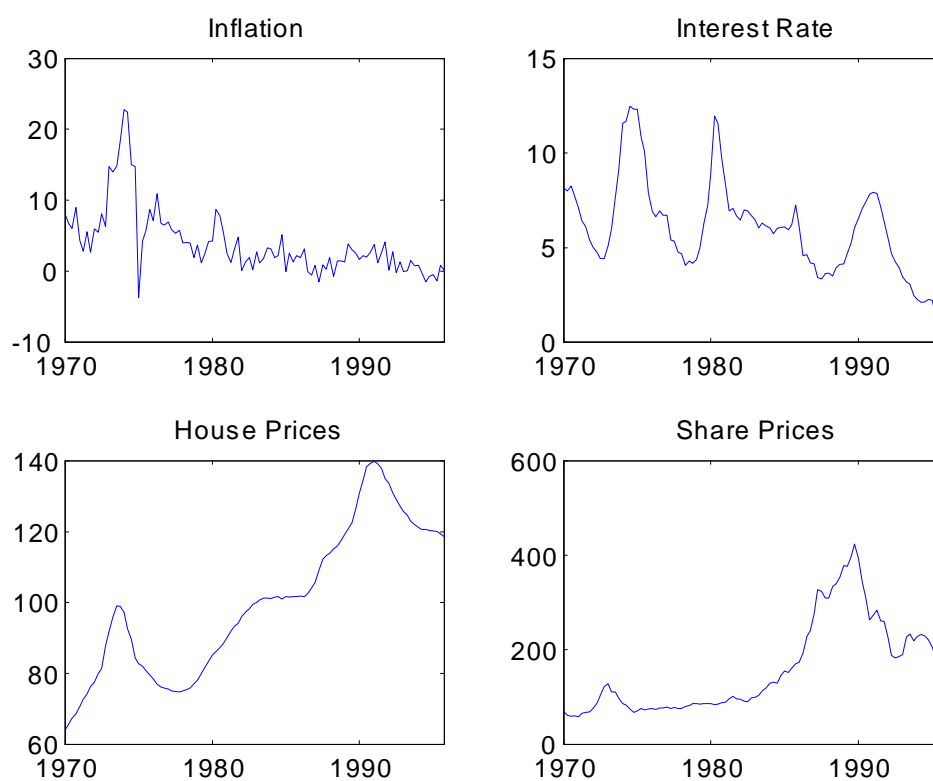


Figure 4.3: Japan

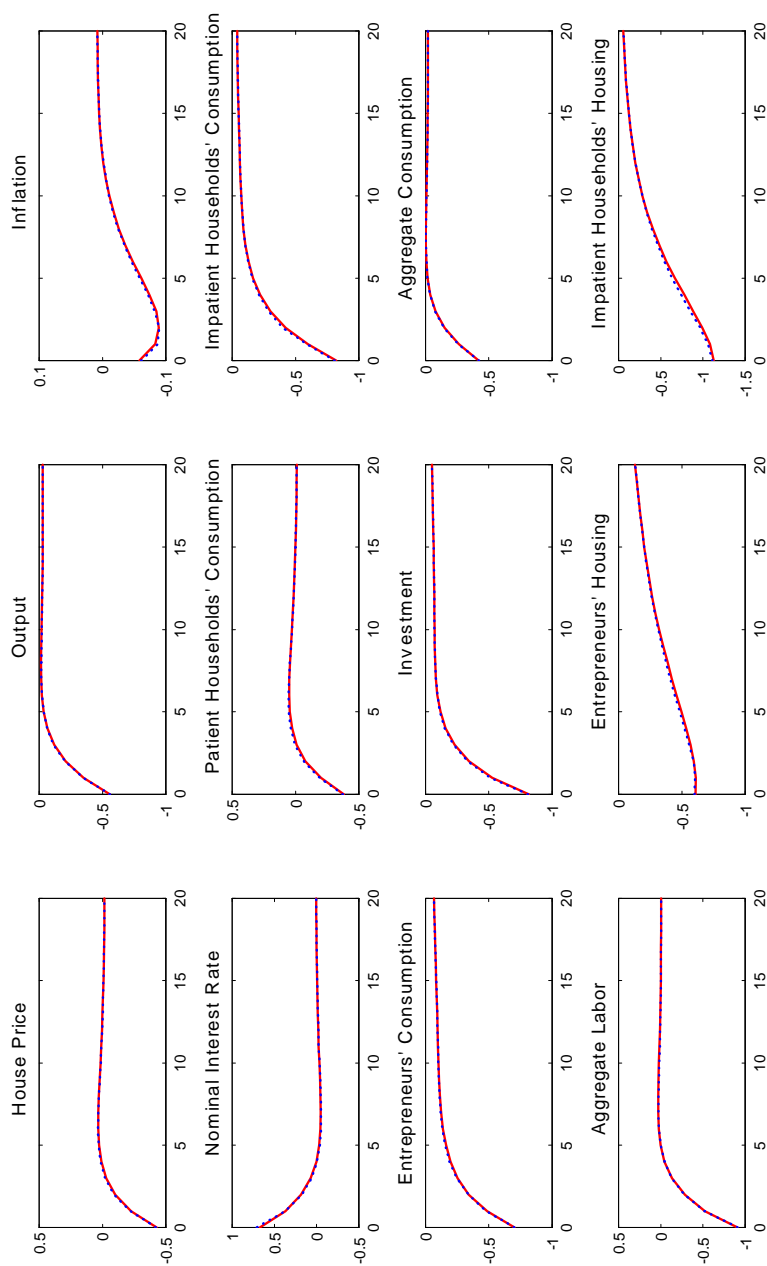


Figure 4.4: Posterior medians for impulse response functions after a monetary policy shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

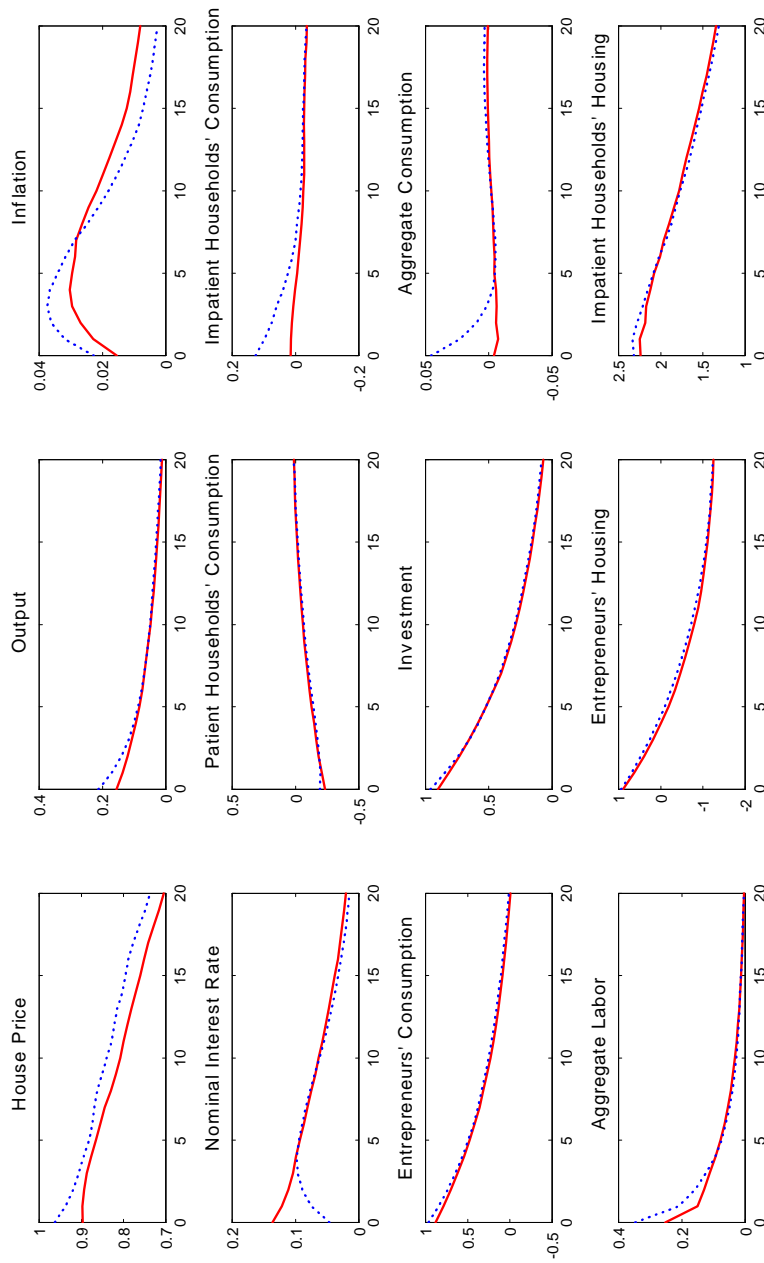


Figure 4.5: Posterior medians for impulse response functions after a house price shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

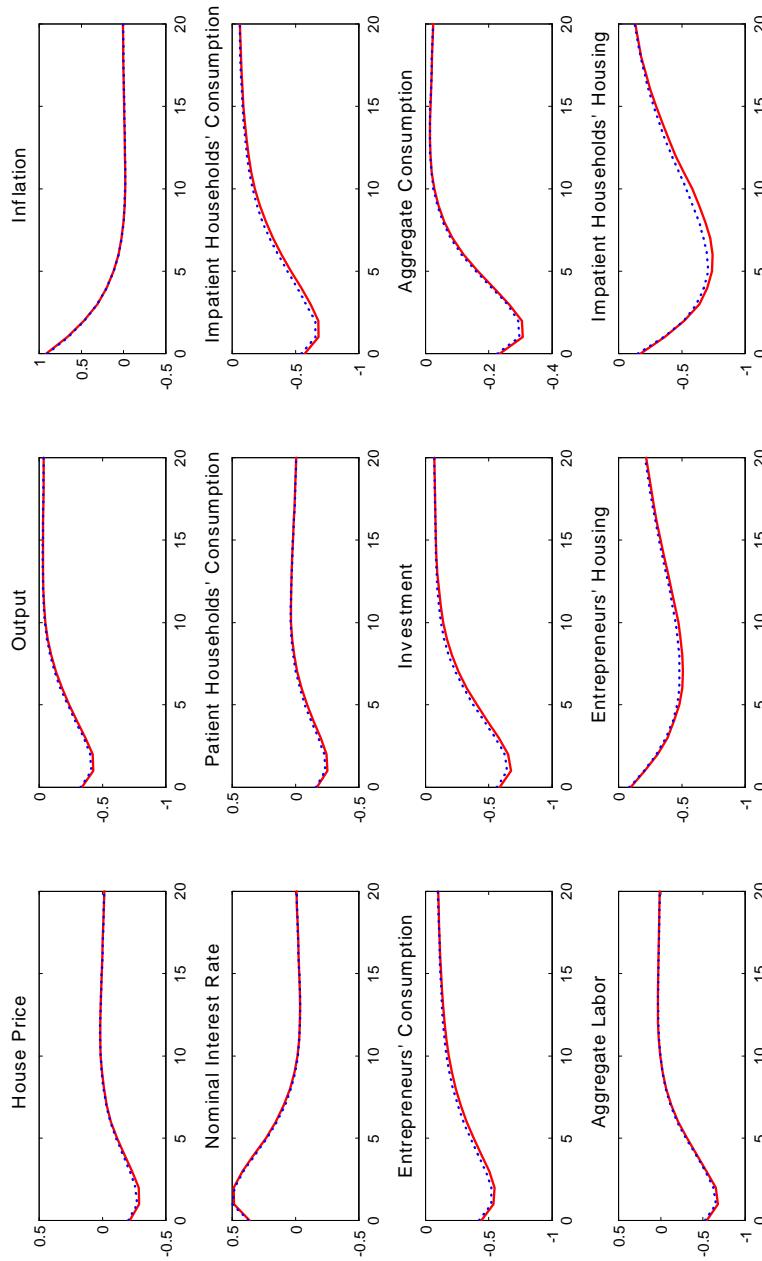


Figure 4.6: Posterior medians for impulse response functions after a price markup shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

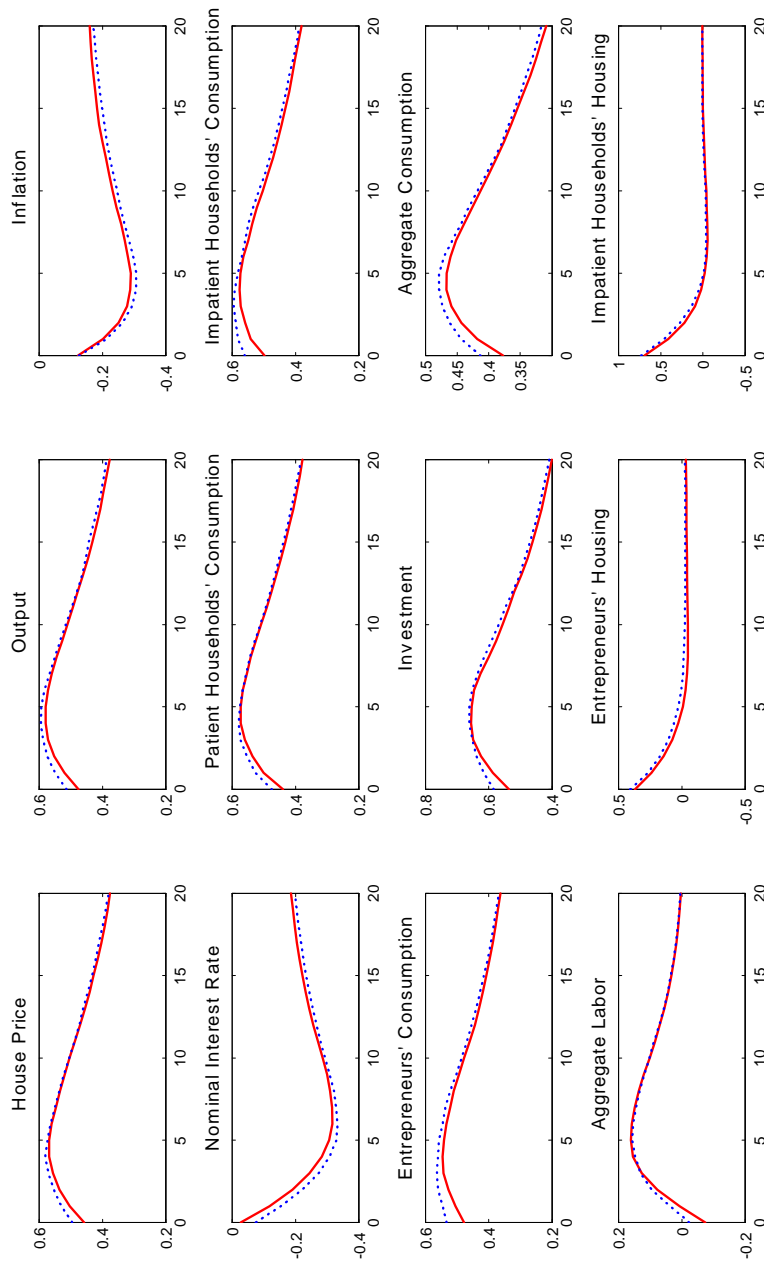


Figure 4.7: Posterior medians for impulse response functions after a technology shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

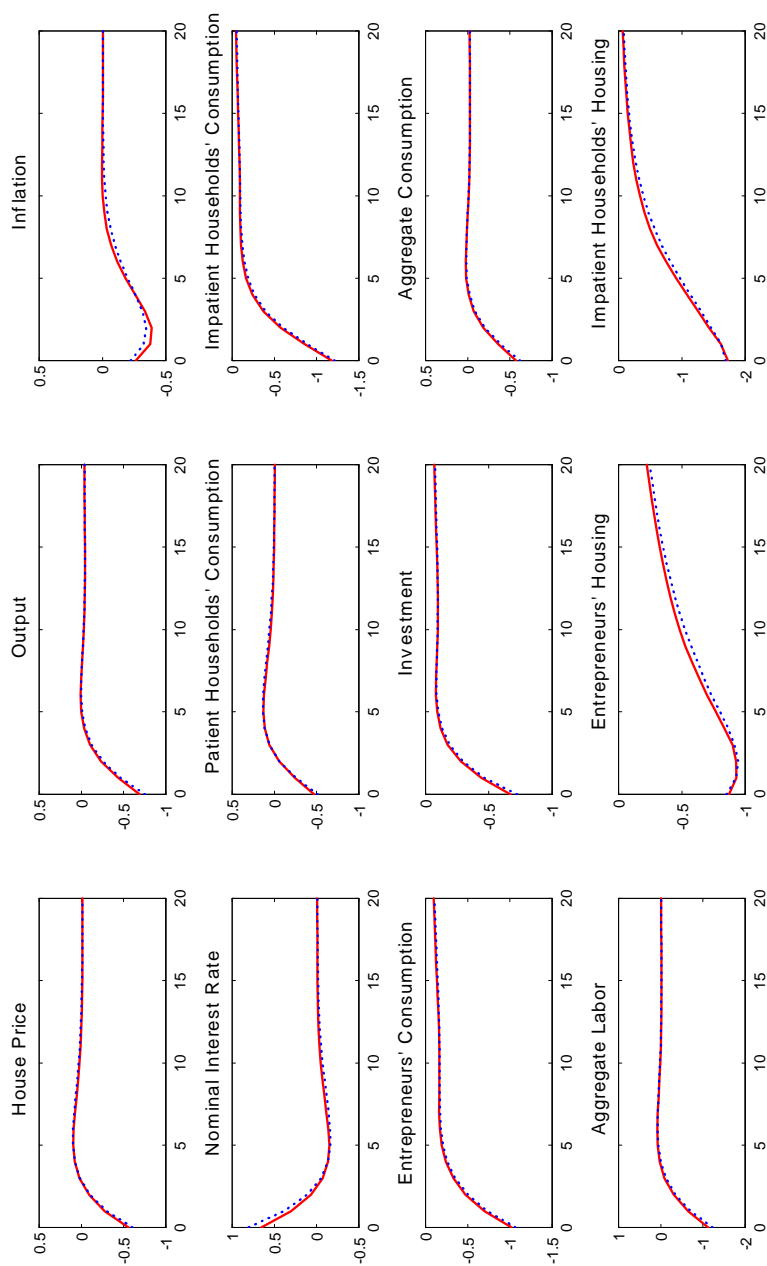


Figure 4.8: Posterior medians for impulse response functions after a monetary policy shock in the U.K. Dotted line: Taylor rule with $\Gamma_q > 0$. Solid line: Taylor rule with $\Gamma_q = 0$.

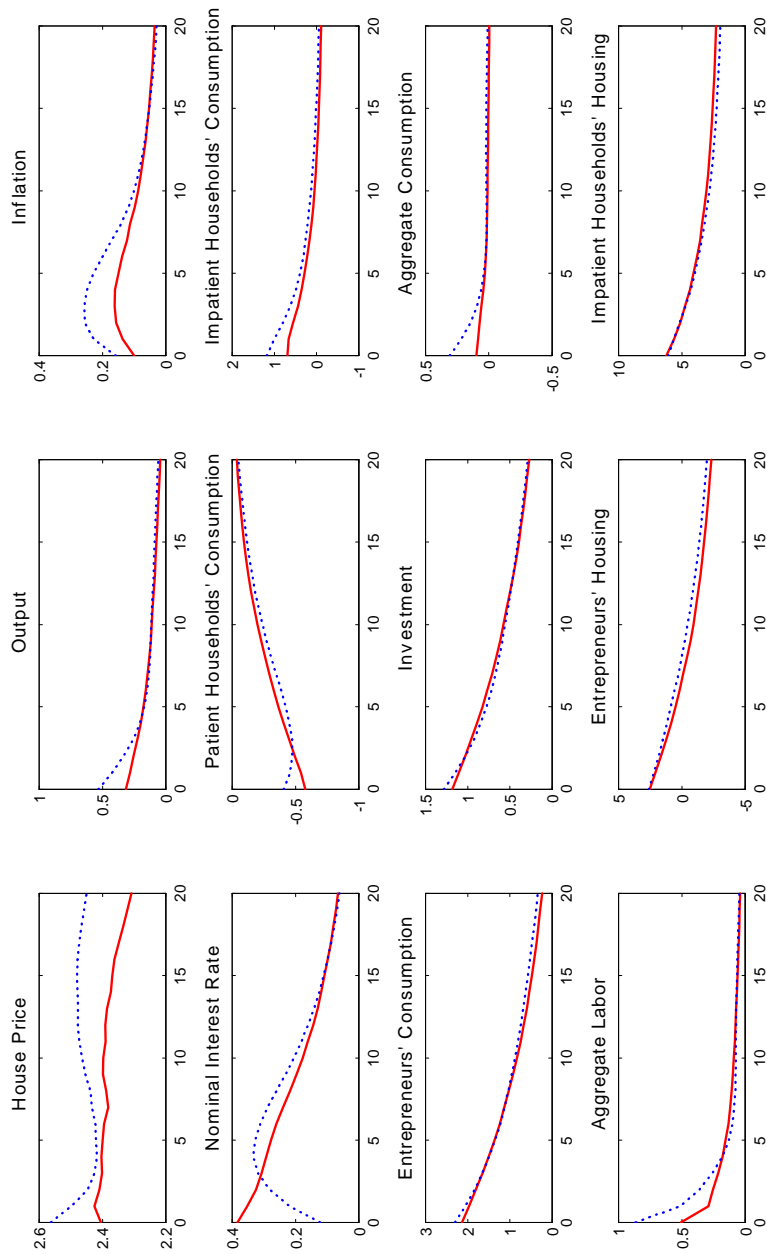


Figure 4.9: Posterior medians for impulse response functions after a house price shock in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

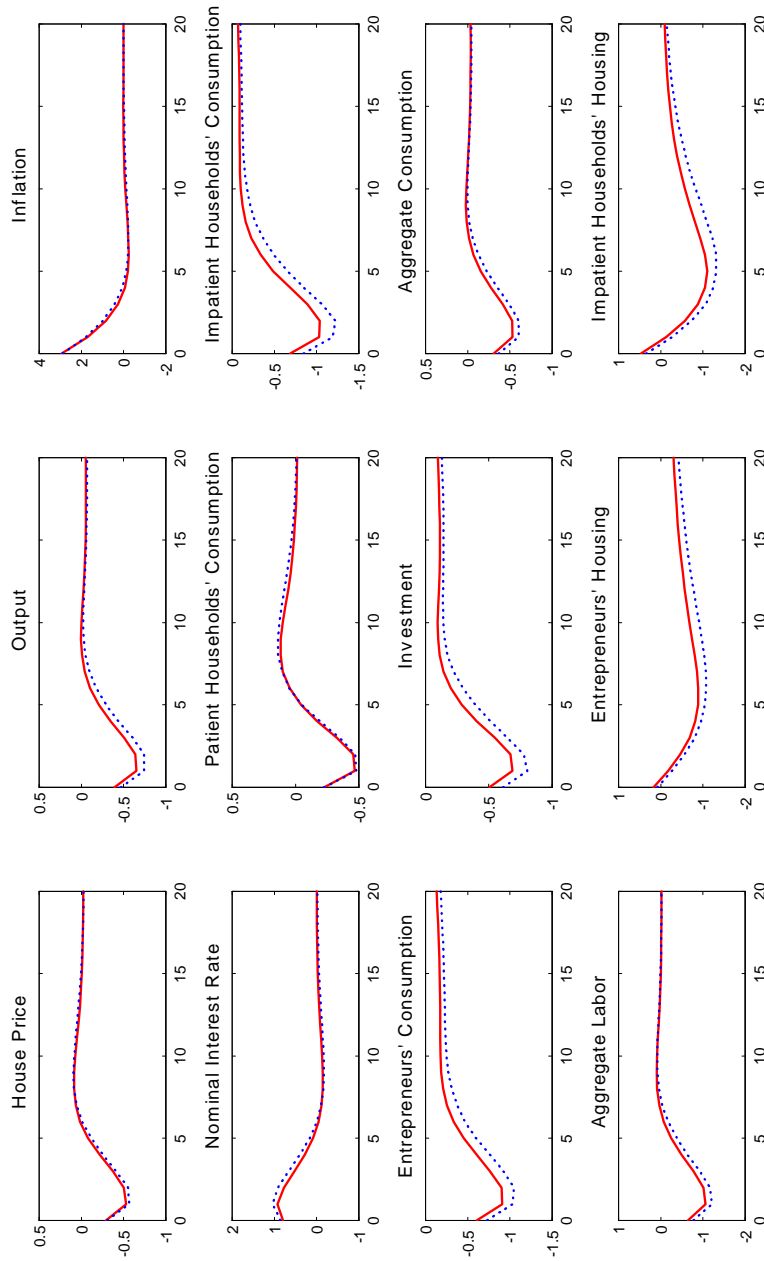


Figure 4.10: Posterior medians for impulse response functions after a price markup shock in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

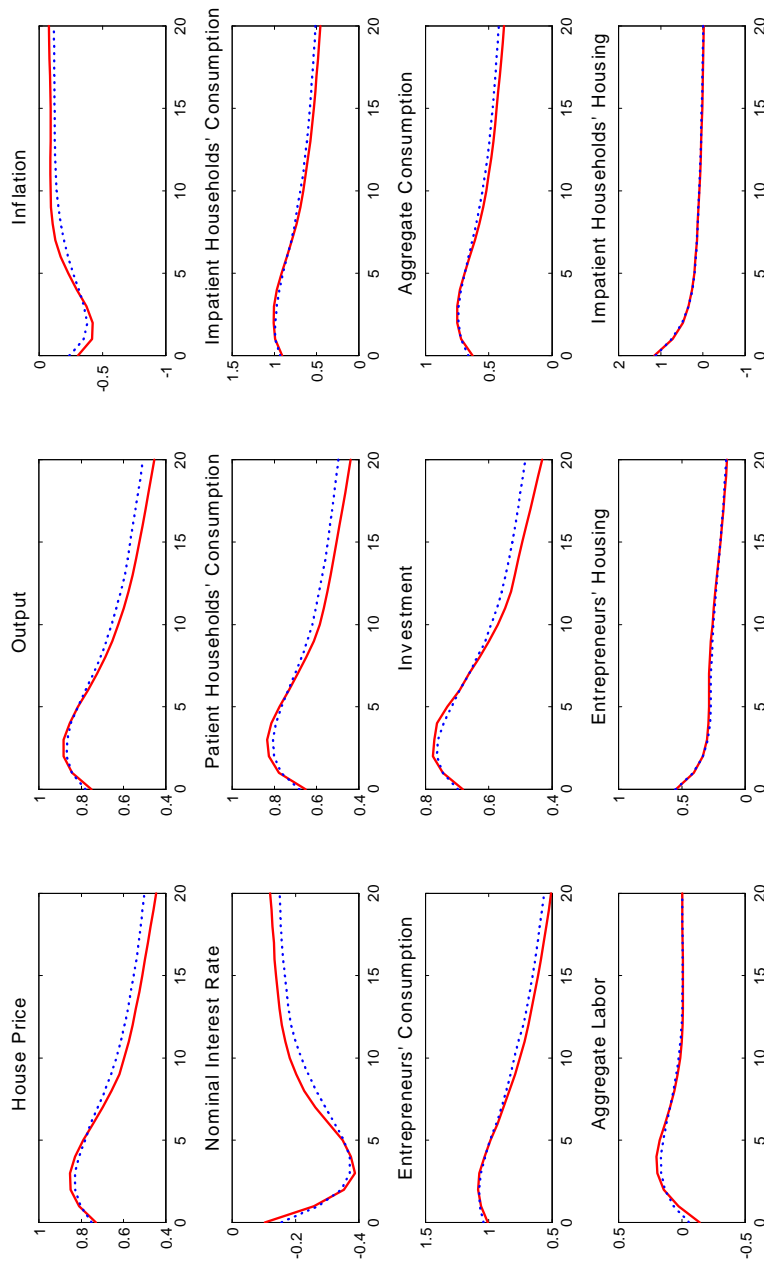


Figure 4.11: Posterior medians for impulse response functions after a technology shock in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

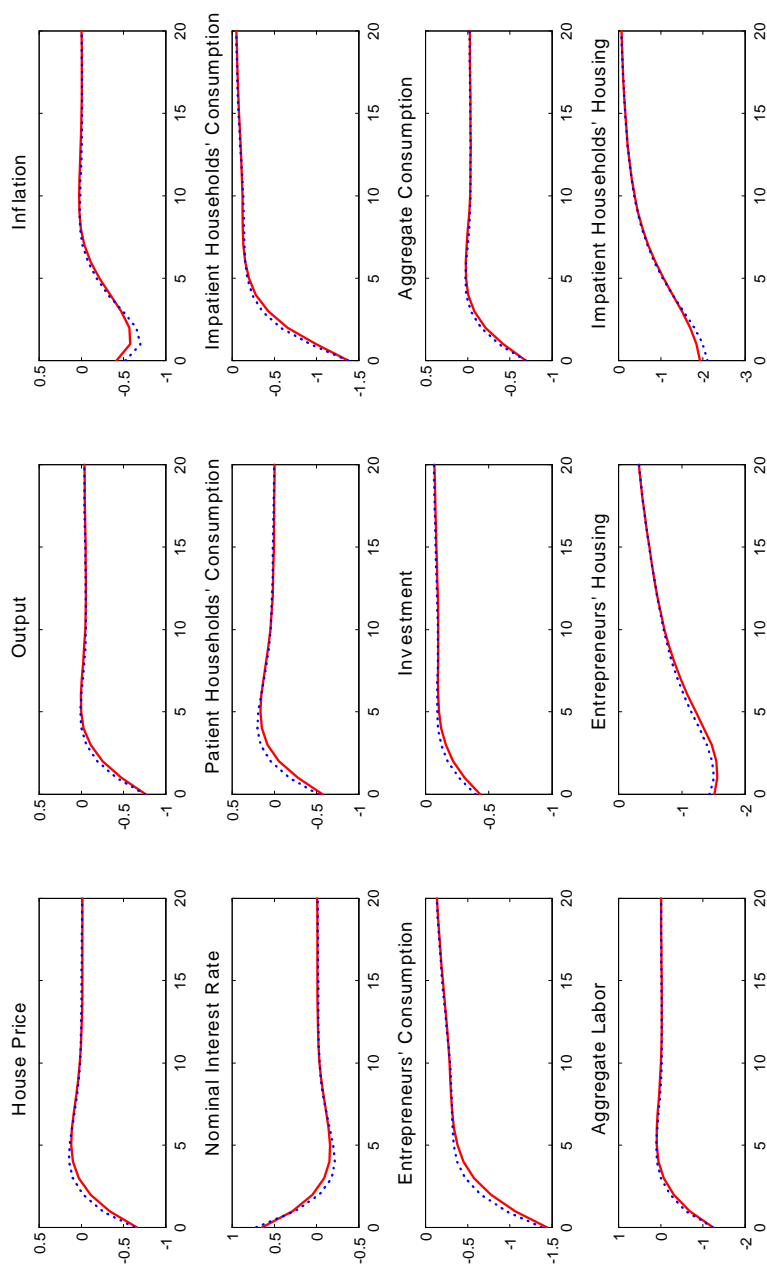


Figure 4.12: Posterior medians for impulse response functions after a monetary policy shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

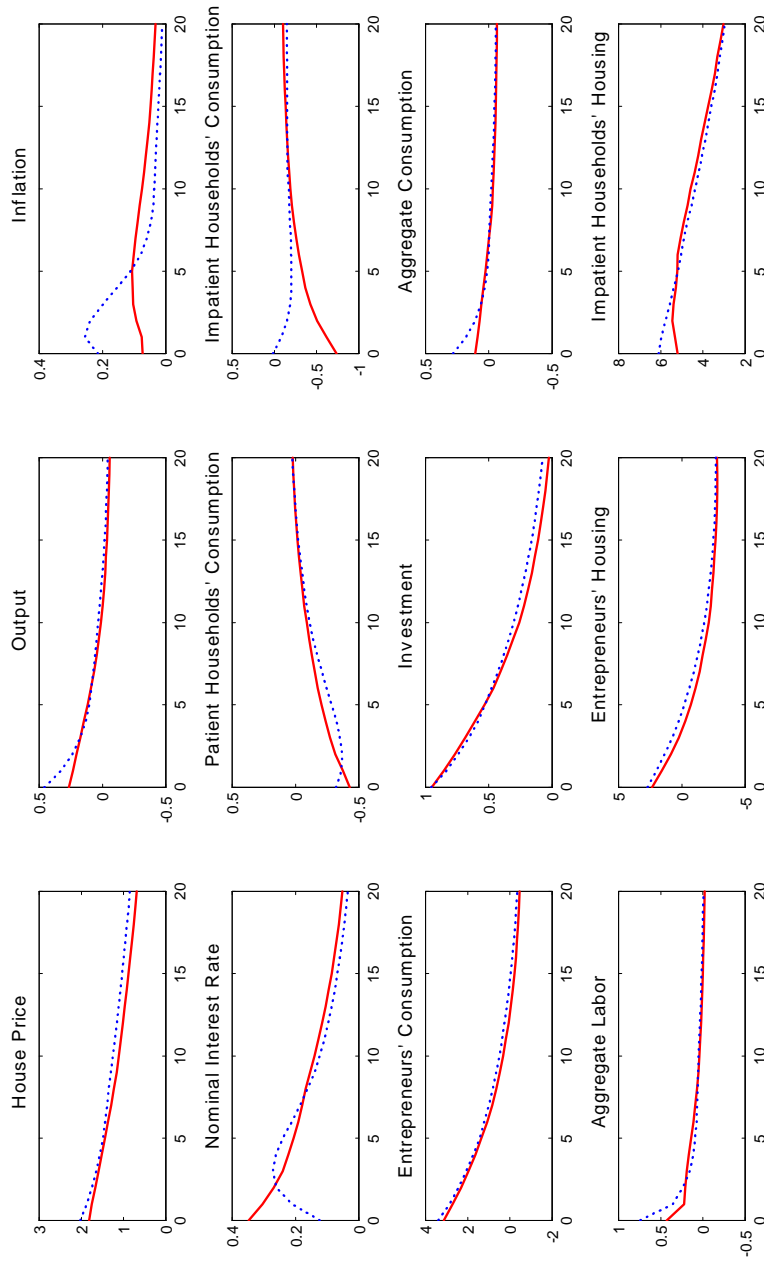


Figure 4.13: Posterior medians for impulse response functions after a house price shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

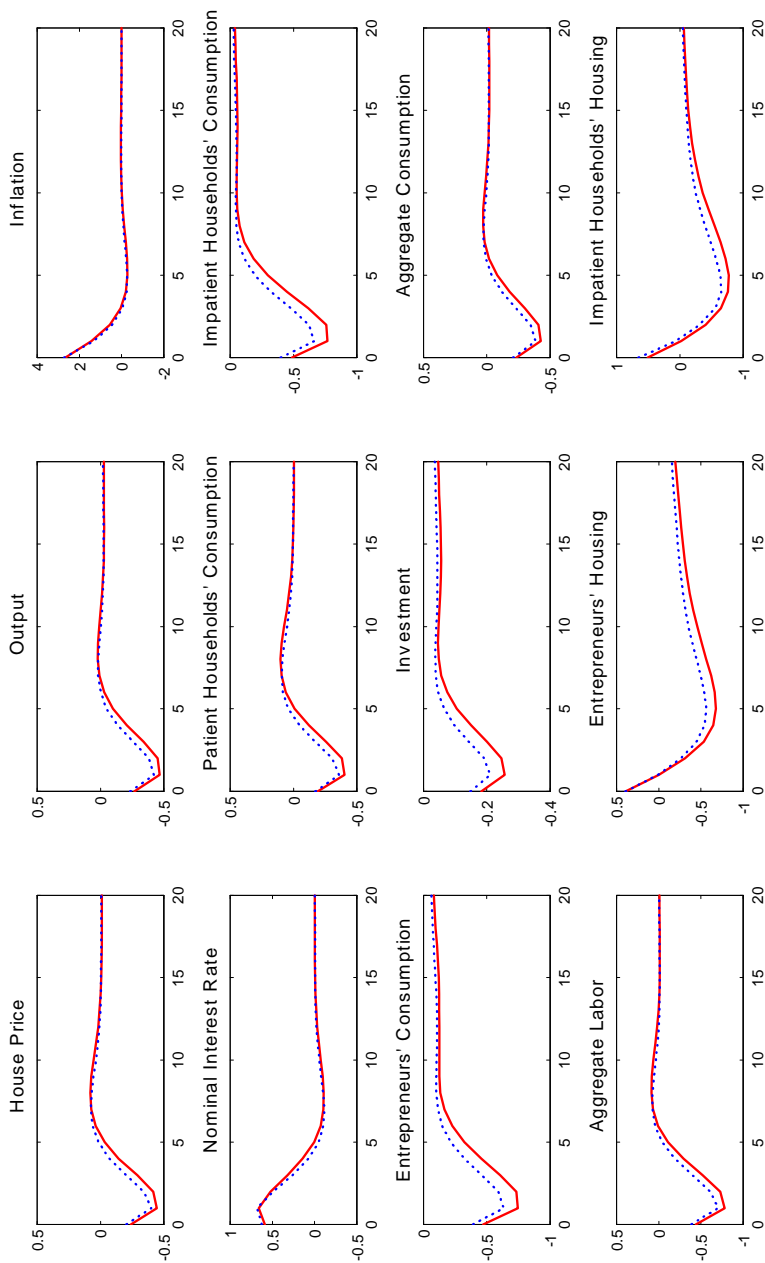


Figure 4.14: Posterior medians for impulse response functions after a price markup shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

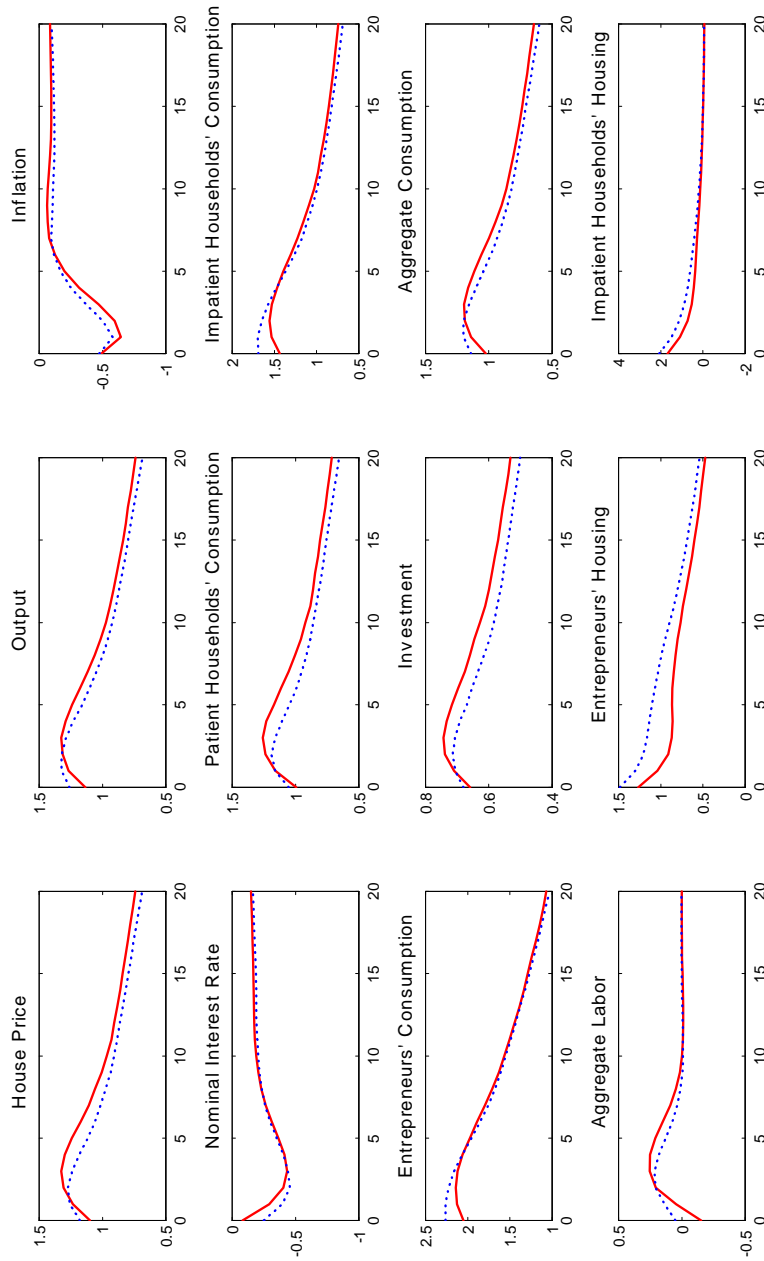


Figure 4.15: Posterior medians for impulse response functions after a technology shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

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