Essays in Macroeconomics:

Author: Pierre De Leo

Boston College Electronic Thesis or Dissertation, 2019

Boston College

The Graduate School of Arts and Sciences

Department of Economics

ESSAYS IN MACROECONOMICS

a dissertation

by

PIERRE DE LEO

submitted in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

April 2019

Essays in Macroeconomics

Pierre De Leo

Advised by Professor Susanto Basu, Associate Professor Ryan Chahrour, and Associate Professor Pablo Guerrón Quintana

Abstract

This dissertation consists of three independent chapters analyzing the sources of business cycles and the role of monetary policy. Taking both closed- and open-economy perspectives, I study the importance of expectations for the empirical identification of economic and policy shocks, the nature of business cycle fluctuations, and the optimal conduct of monetary policy.

The first chapter is titled "International Spillovers and the Exchange Rate Channel of Monetary Policy," and is joint work with Vito Cormun. Motivated by the observation that exchange rate fluctuations largely influence small open economies, we propose a novel approach to separately identify the effects of domestic and external shocks on exchange rates and other macroeconomic variables, thereby uncovering a set of new empirical findings. A first finding is that external shocks account for most of exchange rate fluctuations. Relatedly, the bulk of external shocks is strongly correlated with measures of global risk aversion and uncertainty (e.g. the VIX), and a country's net foreign asset position largely explains the exposure of its exchange rate to external disturbances. A second finding is that

domestic and external disturbances generate very different comovement patterns between interest rates and exchange rates. In particular, unlike domestic shocks, external shocks are associated with large and significant deviations from uncovered interest parity. As a result, an econometrician that fails to properly distinguish between sources of exchange rate fluctuations is bound to obtain puzzling estimates of the exchange rate effects of domestic monetary policy shocks.

These empirical findings have profound implications for models of small open economy and exchange rate determination. In particular, they favor theories in which exchange rates are jointly determined by the risk-bearing capacity in financial markets as well as the extent of a country's financial imbalances. For this reason, we develop a model of the international financial sector that satisfies these features, and embed it in an otherwise standard general equilibrium two-country small open economy model. The key mechanism of the model consists of risk averse traders in the foreign exchange markets that require a premium to hold the currency risk of the small open economy. We show that the proposed model is able to reproduce all the empirical findings documented in the empirical analysis, including the cross-country differences in exposure to external shocks, the role of a country's net foreign asset position, the different responses of interest rates, exchange rates, and currency excess returns across different shocks, as well as the emergence and resolution of the so-called exchange rate response puzzle across different identification approaches.

The second chapter is titled "Should Central Banks Target Investment Prices?" and is joint work with Susanto Basu. The question posed in the title is motivated by the observation that central banks nearly always state explicit or implicit inflation targets in terms of consumer price inflation. To address the question, we develop an otherwise standard dynamic general equilibrium model with two production sectors. One sector produces consumption goods, while the other produces investment goods. In this context, we show that if there are nominal rigidities in the pricing of both consumption and investment goods and if the shocks to the two sectors are not identical, then monetary policy faces a tradeoff between targeting consumption price inflation and investment price inflation. In a model calibrated to replicate the estimated processes of sectoral total factor productivities as well as a set of unconditional business cycle moments, ignoring investment prices typically leads to substantial welfare losses because the intertemporal elasticity of substitution in investment is much higher than in consumption. Based on the model's predictions, we argue that a shift in monetary policy to targeting a weighted average of consumer and investment price inflation may produce significant welfare gains, although this would constitute a major change in current central banking practice.

The third chapter is titled "Information Acquisition and Self-Fulfilling Business Cycles," and is sole-authored work. To study the implications of imperfect information on economic fluctuations, I develop an otherwise standard Real Business Cycle model with endogenous information acquisition, which generates countecyclical firm-level uncertainty and endogenously procyclical productivity, as empirically documented in the literature. The main contribution of this chapter is the observation that this model displays aggregate increasing returns to scale and, potentially, an indeterminate dynamic equilibrium. In fact, an aggre-

gate representation of the model is observationally equivalent to earlier theories of endogenous fluctuations based on increasing returns to scale, but its microeconomic foundations are consistent with empirically observed firm-level returns to scale. In a model calibrated to replicate a set of moments of the empirical distribution of firm-level productivity, self-fulfilling fluctuations are possible. In addition, a Bayesian estimation of the model suggests that non-fundamental shocks explain a significant fraction of aggregate fluctuations.

Acknowledgments

This work would not be possible without the help and support of my advisors, my family, and my friends.

I would like to express my deepest gratitude to my committee for their invaluable support. I thank Susanto Basu for inspiration and guidance throughout these years. Thank you for EC751, a remarkable intellectual experience, and for all you have taught me ever since. I thank Ryan Charhour for the constant, insightful advice. I am grateful for each conversation we had, which greatly shaped my approach to research. I thank Pablo Guerrón Quintana for the precious advice on my research and career. Additionally, I thank my colleagues in the Economics Department for comments on all aspects of this work. In particular, I thank Vito Cormun for the crucial contribution to my scholarly achievements and for our friendship. I am also grateful for financial and fellowship support from the Department of Economics and the Graduate School of Arts and Sciences at Boston College.

Most importantly, thank you, Vera, for unwavering support throughout these years, especially during the hardest times. To my father, thank you for teaching me the value of critical thinking. To my mother, thank you for transmitting me your passion and curiosity. To my sister, thank you for being a great example, and pushing me to be ambitious.

Contents

List of Tables

List of Tables

List of Figures

Chapter 1

International Spillovers and the Exchange Rate Channel of Monetary Policy

1.1 Introduction

Exchange rate fluctuations play a key role in small open economies. Therefore, understanding their sources is central to drawing accurate conclusions about transmission mechanisms. To this end, we propose a novel identification scheme designed to decompose the interest rate and exchange rate effects of domestic and external shocks. Our results rationalize the emergence of recent puzzling estimates of the exchange rate effects of monetary policy, shed light on the determinants of international spillovers, and provide guidance on the mechanisms underlying the cyclical behavior of exchange rates and currency excess returns.

We begin by showing that typical identification approaches within vector autoregressions

(VARs) are bound to confound the endogenous response of domestic variables to external shocks with the effect of domestic shocks. To make our point, we document that the structural shocks identified through recursive ordering and typically interpreted as "monetary policy shocks" of the small open economy predict significant future movement in external variables, including U.S. interest rates and output. Since shocks originating from within a small open economy should not alter world interest rates and incomes, this observation points to a particular misspecification problem: standard identification schemes do not account for a set of external shocks that have a delayed effect on the external variables included in the VAR. We refer to this set of disturbances as "anticipated external shocks."

For this reason, we propose an alternative to the recursive identification scheme. Our identification procedure is based on the premise that shocks originating from within a small economy should not influence world variables *at any horizon.* We identify anticipated external shocks as those that explain most of expected future movements in external variables, and require domestic shocks to be orthogonal to all external disturbances. To identify expected future movements in external variables, we exploit the forward looking nature of interest rates and exchange rates of small open economies. Our main identifying assumption is that small open economies respond to external shocks, but not the reverse. In this context, we demonstrate that typically identified "monetary policy shocks" of small open economies contain a bias if anticipated external shocks contemporaneously spill over into domestic interest rates and exchange rates, and this bias is larger for countries that are more susceptible to external shocks. In this case, an econometrician would confound the monetary policy innovations with the central bank's endogenous response to anticipated external shocks, potentially leading to incorrect conclusions about key transmission mechanisms.

We implement our identification scheme on monthly data for a large set of small open economies and uncover important differences in the comovement patterns implied by different types of shocks. This observation is associated with three related empirical findings.

Our first set of results pertains to the exchange rate response to domestic monetary policy innovations, on which existing empirical evidence is far from conclusive. In particular, Hnatkovska, Lahiri and Vegh (2016) document that the domestic currency tends to appreciate in advanced countries but depreciates in developing and emerging countries in response to a monetary tightening. This evidence, labeled "the exchange rate response puzzle," is primarily based on recursive identification schemes within the framework of VARs, and presents critical challenges for standard open economy theories. We find that the exchange rate response puzzle disappears after accounting for the spillover effects of anticipated external shocks: in most countries, a monetary policy contraction is associated with a significant appreciation of the nominal exchange rate, with a somewhat larger quantitative effect for advanced economies: after a 1% increase in the interest rate the exchange rate appreciates by around 2.5% in advanced economies and by around 1% in developing and emerging economies. Instead, a puzzle arises under a recursive identification scheme because it commingles domestic and external shocks, which give rise to opposite comovements between interest rates and exchange rates. A related finding is that domestic monetary policy shocks are not the main driver of exchange rate fluctuations, especially in developing and emerging economies.

The second set of results have a bearing on the nature of external shocks and the cross-country heterogeneity in their spillover effects. We document that anticipated external shocks explain a large fraction of the fluctuations of interest rates and exchange rates in our sample of small open economies. These shocks are strongly correlated with the VIX, a proxy for global risk aversion and uncertainty, as well as U.S. macroeconomic variables.[1] In addition, an external shock that signals an improvement in the U.S. economic outlook spills over into small open economies in the form of a significant currency appreciations and interest rate declines – the comovement the literature had attributed to domestic monetary policy shocks. Crucially, we find considerable heterogeneity in spillover effects across countries. In particular, exposure to anticipated external shocks is stronger for countries that feature large net foreign liabilities (usually developing and emerging economies).

The third set of empirical results concerns the sources of cyclical deviations from uncovered interest parity (UIP). UIP deviations are often used as a metric to discriminate across different classes of open economy models, with potentially different policy implications. While the relevant literature has generally documented their *unconditional* properties, we provide new *conditional* evidence indicating that external shocks are the main source of UIP deviations. In fact, we find robust evidence of large deviations from UIP in response to anticipated external shocks, but not in response to domestic (monetary policy) shocks,

[1] Anticipated external shocks give rise to a positive comovement among U.S. output, inflation, and Federal Funds rate. Thus, the bulk of international spillovers (operating through the exchange rate) do not appear to be driven by U.S. monetary policy shocks.

suggesting that country-specific UIP shocks are not a satisfactory representation of the data.[2]

Taken together, these findings indicate no considerable differences in the way the transmission mechanism of domestic monetary policy works across different countries. On the contrary, we find substantial differences in countries' exposure to external shocks, and present evidence pointing to financial imbalances as being an important element of the transmission of international shocks to the domestic economy.

Our findings provide new disciplining evidence for models of international business cycles and exchange rate determination. Thus, we present a model that highlights the drivers and transmission mechanisms that are necessary to reproduce our findings. We build a two-country small open economy model based on Galí and Monacelli (2005) and De Paoli (2009), in which economic developments in the large economy (the U.S.) affect the small economy, but not vice versa.[3] Importantly, we depart from the standard framework by assuming that international financial markets are segmented and financial traders are averse to hold currency risk along the lines of Gabaix and Maggiori (2015).[4] In addition to the path of interest rate differentials, equilibrium exchange rates are determined by global risk aversion and the net foreign asset position of the small open economy – the relevant measure of external imbalances in our model.

Besides monetary policy innovations in both countries, we model a shock to global risk

[2] Thus, we find limited evidence of the "delayed overshooting puzzle" (see Eichenbaum and Evans, 1995) in small open economies.
[3] This environment is consistent with our main empirical identification restrictions.
[4] See also Jeanne and Rose (2002).

aversion that influences the static and dynamic decisions of U.S. traders and households. We show that this shock generates responses that closely mimic those that we find in the empirical analysis for anticipated external shocks, including the dynamic pattern of currency excess returns and the cross-country heterogeneity in exchange rate responses. When global risk aversion declines, U.S. output and inflation increase, and this brings about a gradual increase in the Federal Funds rate (due to interest rate smoothing). Notwithstanding the expected increase in the Federal Funds rate, higher traders' risk-bearing capacity and improved domestic net foreign asset position lead to a large currency appreciation in the small open economy, accounted for by a sharp decline in ex ante excess returns. Crucially, this effect is larger for net-debtor countries (usually developing and emerging economies), as they are more susceptible to changes in traders' risk aversion. In response to this shock, domestic central banks cut their policy rate to avoid excessive fluctuations in consumer price inflation, in line with our empirical evidence. In this framework, domestic monetary policy shocks have no effect on global risk aversion, and a small impact on a country's financial imbalances. As a result, a monetary policy contraction leads to an impact appreciation of the domestic currency, and to very small deviations from UIP. Overall, this parsimonious framework is therefore capable of reproducing the comovements that we document empirically, including the dynamic patterns of UIP deviations. We emphasize that asset imbalances and global risk aversion are central to understand exchange rate fluctuations and the role of monetary policy.

Furthermore, we use the model to test the empirical approach we take in decomposing the various sources of shocks. To do so, we simulate data from our estimated model and perform a Monte Carlo estimation exercise. We find that our identification strategy succeeds in recovering the effects of both external and domestic shocks: the identified monetary policy shock maps into the small open economy monetary policy shock in the model, while the anticipated external shock maps into the innovation to global risk aversion, providing further support for our identification scheme. To the contrary, a recursive VAR analysis on model generated data reproduces the exchange rate puzzle, exactly because it conflates domestic and external shocks.

Related literature This paper is related to several strands of the literature concerned with understanding open economy fluctuations.

First, we aim to shed light on the empirical evidence on the exchange rate response to domestic monetary policy. In their seminal article, Eichenbaum and Evans (1995) show that an orthogonalized contractionary shock to the Federal Funds rate leads to a persistent and significant appreciation of the U.S. nominal exchange rate. Using a structural VAR approach along the lines of Sims and Zha (2006), Kim and Roubini (2000) find that contractionary monetary policy innovations induce nominal appreciations of the exchange rates in the non-U.S. G7 economies.[5] Recently, using a recursive VAR analysis, Hnatkovska, Lahiri and Vegh (2016) document a new pattern of the exchange rate response: they confirm that the exchange rate appreciates in industrial economies, but it depreciates in developing and

[5] See also Cushman and Zha (1997) and Faust and Rogers (2003).

emerging countries after a monetary policy contraction.[6,7]

We contribute to this literature by highlighting the challenge to identification represented by anticipated external shocks. These are shocks that originate in the global economy, immediately spill over into small open economies, but have no immediate effect on the external variables – such as U.S. macroeconomic variables – included in the VAR. We propose a method to address this challenge, and show that anticipated external shocks are responsible for the bulk of the puzzling exchange rate responses. By and large, this reveals that the so-called exchange rate response puzzle is likely to be a product of misspecification rather than a data fact.[8]

Second, this paper is related to the literature on the empirical importance of spillover effects of external shocks, recently exemplified by Bruno and Shin (2015) and Rey (2015), who document large financial spillovers associated with variations in global risk aversion.[9] While we also emphasize the role of global risk aversion, our paper highlights that the spillover effects of external shocks into exchange rates are associated with a country's net foreign asset position. Our results are thus in line with Della Corte, Riddiough and Sarno's (2016) evi-

[6] The results of Hnatkovska, Lahiri and Vegh (2016) are robust to controlling for a large set of domestic variables as well as using alternative identification strategies that allow for a non-zero contemporaneous response of the interest rate to exchange rates.

[7] Using a high frequency identification scheme, Kohlscheen (2014) finds similar puzzling responses for three developing countries.

[8] Cushman and Zha (1997) also warn about the importance of accounting for external shocks in the VAR identification of domestic monetary policy innovations. Their paper focuses on Canadian data and assumes block exogeneity, which is rejected in small-scale VARs.

[9] Other papers that study the effect of various U.S. or global shocks on small open economies include Canova (2005), Uribe and Yue (2006), Mackowiak (2007), Akinci (2013), Levchenko and Pandalai-Nayar (2015), Ben-Zeev, Pappa and Vicondoa (2016), Vicondoa (2016), Davis and Zlate (2017), Iacoviello and Navarro (2018), Cesa-Bianchi, Ferrero and Rebucci (2018), Bhattarai, Chatterjee and Park (2017), and Fernández, Schmitt-Grohé and Uribe (2016)

dence that investors' exposure to countries' external imbalances explains the cross-sectional variation in currency excess returns. We highlight the joint role of financial markets' risk bearing capacity and domestic monetary policy in generating these patterns.

Third, our paper is related to a literature concerned with the ability of structural DSGE models to account for the substantial influence of external disturbances. Related to our paper, Georgiadis and Jancoková (2017) show that many estimated New Keynesian DSGE models produce "monetary policy shock" series that are significantly correlated across countries.[10] They interpret this evidence as indicating that these models erroneously label foreign monetary policy shocks as domestic because they lack mechanisms of international financial spillovers. Unlike Georgiadis and Jancoková (2017) and the related literature, we focus on small-scale VARs and study the implications for the identification of the exchange rate channel of monetary policy. In this context, we find that recursive identification schemes within VARs produce "monetary policy shock" series that predict significant changes in external variables because these VARs contain an external shock that is not properly accounted for.[11]

Fourth, our paper is related to the vast literature that aims to rationalize the observed cyclical deviations from UIP. We provide new evidence on UIP deviations pointing to these being predominantly due to global shocks.[12] Using these targets in our analysis, we reach

[10] See also Justiniano and Preston (2010), Guerron-Quintana (2013) and Alpanda and Aysun (2014)

[11] Jääskelä and Jennings (2011) and Carrillo and Elizondo (2015) use data simulated from specific models to examine the performance of different VAR schemes in recovering the effects of monetary policy in small open economies.

[12] Using data from Turkey, di Giovanni et al. (2017) document the presence of significant UIP deviations at both firm and country level, and show that these are strongly correlated with movements in the VIX.

similar conclusions to Itskhoki and Mukhin (2017) on the key drivers of exchange rate fluctuations. In particular, our global risk aversion shock is a specific microfoundation to Itskhoki and Mukhin's financial shock (see also Gabaix and Maggiori, 2015). By solving our model around a non-zero steady-state net foreign asset position, we show that this shock influences small open economies differently according to their degree of external indebtedness, in line with our empirical findings.

Last, our paper's identification procedure is related to the rapidly growing literature on the VAR identification of anticipated ("news") shocks (see Beaudry and Portier, 2014, for a recent survey of the literature). In particular, our identification scheme is analogous to Barsky and Sims (2011). While this literature focuses on the closed economy effects of anticipated TFP movements, we are interested in identifying the role of the spillover effects of the whole set of anticipated external shocks on a large set of small open economies. To do so, we exploit the fact that the Federal Funds rate is inherently endogenous to U.S. economic conditions and plausibly exogenous to idiosyncratic economic conditions of small open economies. In addition, we are equally concerned about identifying the variation in the domestic interest rate that is orthogonal to the whole set of external shocks, and how it is related to shocks extracted using a recursive identification scheme. This methodology is likely applicable beyond the specific questions addressed in this paper.[13,14]

[13] This method of identification of domestic monetary policy shocks is not confined to a three-variable VAR. In fact, we apply it to larger VARs by imposing additional identification restrictions on the effect of various domestic shocks.

[14] Levchenko and Pandalai-Nayar (2015) recently adopt a similar approach to cleanse an expectational variable from unanticipated and anticipated TFP shocks.

1.2 Econometric strategy

In this section, we begin by describing our dataset. We then illustrate the problems associated with common identification strategies of monetary policy in small open economies, and propose an alternative identification strategy designed to resolve these problems.

1.2.1 Dataset

Our data construction and sample selection largely follows the approach of Hnatkovska, Lahiri and Vegh (2016). We use a large sample of countries over the period 1974:1-2010:12 for which monthly data on exchange rates and interest rates are available, focusing on countries and time periods that are characterized by a flexible exchange rate regime, following Reinhart and Rogoff's (2004) classification. Further details on data sources and selection criteria are reported in Appendix A.1. The overall dataset features 25 industrial country-episode pairs and 45 developing and emerging country-episode pairs, for a total of 70 country-episode pairs. While we present the main results for this extended sample of countries, our impulse response analysis focuses on six of the G7 economies (United Kingdom, Canada, Japan, Italy, Germany and France) and the six largest developing and emerging economies in our sample (South Africa, Philippines, Indonesia, Brazil, South Korea and Mexico).[15]

[15] We follow the relevant literature in grouping developing and emerging economies together, and use "developing" to refer to this group of countries.

1.2.2 A three-variable small open economy VAR

Our baseline is a three-variable VAR, featuring (home and foreign) interest rates and the exchange rate. In later sections, we will also present findings obtained from larger VARs, featuring additional macroeconomic and financial variables. We focus on a three variable VAR as the baseline, since adding variables does not affect our key points about identification. In addition, a three-variable VAR allows us to transparently compare the implications of different identification strategies, as well as relate to results obtained in standard UIP regressions.

Consider a three-variable VAR with the Federal Funds rate ($r^{\star}$), the policy-controlled interest rate of small open economy k (r_k), and the logarithm of the bilateral nominal exchange rate between country k's currency and the U.S. dollar (s). Exchange rates are in domestic currency units per US dollar, so that an increase is a depreciation of local currency relative to the US dollar. The model is specified in levels and the number of lags is chosen according to the Akaike information criterion. Unlike the case of a vector error correction model, the estimators of the impulse responses of a VAR in levels are consistent in the presence of nonstationary but cointegrated variables where the form of cointegration is unknown. Furthermore, estimators are consistent even in the absence of a cointegrating relations among the variables, provided that enough lags are included in the VAR (see Hamilton, 1994).

Thus, let $y_t \equiv [r_t^{\star} \;\; r_{k,t} \;\; s_t]'$ be the 3×1 vector of observable variables that have length T. The Federal Funds rate is ordered first, the policy-controlled interest rate of country k

is ordered second, and the log of the nominal exchange rate is ordered last. Denote by

$$y_t = B(L)u_t$$

the reduced-form moving average representation in the levels of the observable variables, formed by estimating an unrestricted VAR in levels. The relationship between reduced-form innovations and structural shocks is given by:

$$u_t = A_0\varepsilon_t \tag{1.1}$$

which implies the following structural moving average representation:

$$y_t = B(L)A_0\varepsilon_t. \tag{1.2}$$

We assume that the structural shocks are orthogonal with unitary variance, so that the impact matrix A_0 satisfies $A_0A_0' = \Sigma$, where Σ is the variance-covariance matrix of innovations. In order to identify A_0, one needs to impose $n(n-1)/2$ additional restrictions, where n is the number of variables included in the VAR.

A common recursive identification scheme. The typical exclusion restrictions consist in assuming that the impact matrix is lower triangular, that is

$$u_t = \begin{bmatrix} a_1 & 0 & 0 \\ a_2 & a_3 & 0 \\ a_4 & a_5 & a_6 \end{bmatrix} \widetilde{\varepsilon}_t \tag{1.3}$$

which is estimated with the Cholesky decomposition of Σ. From Eq. (1.2), the restrictions on the impact matrix A_0 imply that the Federal Funds rate can respond contemporaneously only to its own innovations which are captured by the first element of the vector $\widetilde{\varepsilon}_t$. The policy controlled interest rate of the small open economy is not allowed to react on impact to movements in the nominal exchange rate while it can respond to unanticipated movements in the Federal Funds rate. The second element element of the vector of structural shocks $\widetilde{\varepsilon}_t$ is thus typically interpreted as the monetary policy shock of the small open economy. In this context, a domestic monetary policy shock influences the policy rate of the small open economy (and possibly the exchange rate) contemporaneously, has no effect on the Federal Funds rate contemporaneously, and leaves the response of the Federal Funds rate unrestricted in the months following the shock.

Before discussing the estimated exchange rate response to monetary policy, we ask whether the identified monetary policy shocks are consistent with the assumptions of a small open economy. To this end, Figure 1.1 depicts the median impulse response of the Federal Funds rate to a domestic monetary policy shock. Under a recursive identification, a contractionary domestic monetary policy shock leads to a significant and persistent decline

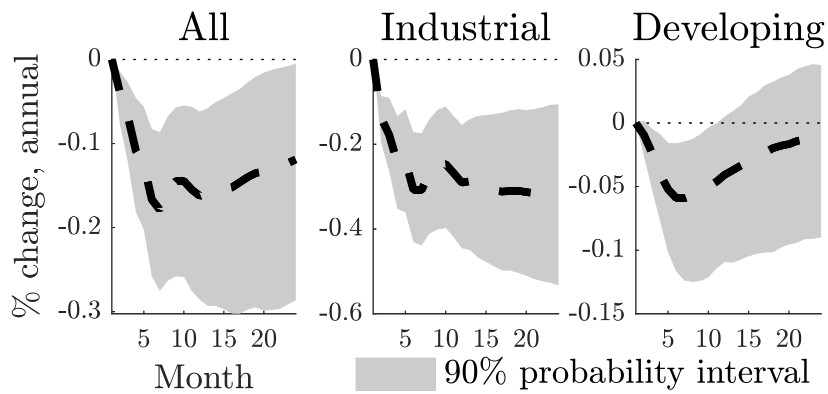


Figure 1.1: Federal Funds rate response to a 1% contractionary domestic monetary policy shock (recursive identification scheme)

Note: The shaded areas are the 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR.

of the Federal Funds rate, the external variable of our VAR.

In addition, in Appendix A.2.1 we perform a test of Granger causality that consists in regressing the Federal Funds rate or the cyclical component of U.S. industrial production on up to 36 lags of the identified monetary policy shock. The monetary policy shock identified through recursive ordering appears to systematically predict future movements in both external variables, especially when longer horizons are part of the regression.[16]

There are two possible interpretations of the results in Figure 1.1. First, the U.S. economy, and, in turn, the Federal Reserve, may respond to disturbances that originate in small open economies, and in particular to their monetary policy innovations. Second, monetary policy in small open economies may respond to external shocks that affect the world interest rate with some delay. While both interpretations are valid in principle, we note that the

[16] For the regression with the Federal Funds rate, we reject the null of no Granger causality in all countries at 5% level of significance with the exception of South Africa and Brazil. Somewhat similar figures appear when we perform the Granger causality test using the cyclical component of U.S. industrial production.

first interpretation is both contrary to conventional wisdom and inconsistent with the very premise of a *small* open economy by which domestic shocks do not alter world interest rates and incomes.

We thus subscribe to the second interpretation, and argue that the domestic monetary policy shocks identified through recursive schemes partly capture the endogenous response of domestic central banks to external shocks that influence the world interest rate with some delay. For this reason, we will refer to these shocks as "*anticipated* external shocks." In addition, we note that these results question the applicability of the common block exogeneity restriction. In the context of the baseline VAR, block exogeneity is equivalent to setting the coefficients on domestic variables in the Federal Funds rate equation to zero. Under the null of no anticipated external shocks, these coefficients are in fact zero. However, if anticipated effects exist, as documented in Figure 1.1, these coefficients are not zero, and applying block exogeneity would be equivalent to imposing a counterfactual restriction.[17] While block exogeneity implies a restriction on the reduced-form parameters of the VAR, our identification strategy imposes a restriction on the propagation of shocks.

1.2.3 An alternative identification scheme

Within the above three-variable VAR, we propose an identification strategy designed to disentangle the effects of anticipated external shocks from those of monetary policy innovations of country k. Our approach is agnostic in that we impose a minimal set of restrictions

[17] It is important to stress that the above statements are conditional on the information set spanned by the three variables included in the three-variable VAR outlined above.

consistent with virtually all small open economy models. The economic meaning of these restrictions is that shocks that originate in the small open economy have no influence on the world interest rate *at any horizon*. Specifically, we assume that the external variable in the VAR, the Federal Funds rate, is properly characterized as following a stochastic process driven by unanticipated and anticipated shocks, and that the latter display no contemporaneous effect on the Federal Funds rate.[18] We refer to anticipated movements in the Federal Funds rate as anticipated external shocks. The domestic monetary policy shock of the small open economy is then identified as the linear combination of the VAR innovations that is orthogonal to unanticipated and anticipated external shocks.

To implement our identification scheme in the three-variable VAR presented above, we note that the impact matrix A_0, defined in Eq. (1.1), is unique up to any rotation D of the structural shocks. Specifically, for any 3×3 orthonormal matrix D, the entire space of permissible impact matrices can be written as $\widetilde{A}_0 D$, where $\widetilde{A}_0$ is an arbitrary orthogonalization (e.g. the one implied by a recursive identification scheme).

Here, the h-step ahead forecast error is

$$y_{t+h} - E_{t-1} y_{t+h} = \sum_{\tau=0}^{h} B_\tau \widetilde{A_0} D \varepsilon_{t+h-\tau}$$

where B_τ is the matrix of moving average coefficients at horizon τ. The share of the forecast

[18] We find that the results are robust to relaxing this contemporaneous restriction.

error variance of variable i attributable to the structural shock j at horizon h is then:

$$\Omega_{i,j}(h) = \frac{\sum_{\tau=0}^{h} B_{i,\tau}\widetilde{A}_0\gamma\gamma'\widetilde{A}_0'B_{i,\tau}'}{\sum_{\tau=0}^{h} B_{i,\tau}\Sigma B_{i,\tau}'}$$

where γ is the j-th column of D, while $B_{i,\tau}$ corresponds to the i-th row of B_τ.

Our primary objective is to identify the monetary policy shock of country k such that it is orthogonal to unanticipated and anticipated external shocks. To do so, we adopt a procedure that extends the identification scheme proposed by Barsky and Sims (2011) and that can be explained as composed of two steps.[19] First, we recover the unanticipated and the anticipated movements in the Federal Funds rate. The former is identified as the orthogonal innovation in $r^{\star}$. The latter is identified as the shock that maximizes the contribution to the forecast error variance of the Federal Funds rate up to a truncation horizon H, subject to the restriction that this shock has no contemporaneous effect on the Federal Funds rate. Formally, the identification of the anticipated external shock boils down to solving the following maximization problem:

$$\gamma* = \arg\max \sum_{h=0}^{H} \Omega_{1,2}(h) = \frac{\sum_{\tau=0}^{h} B_{i,\tau}\widetilde{A}_0\gamma\gamma'\widetilde{A}_0'B_{i,\tau}'}{\sum_{\tau=0}^{h} B_{i,\tau}\Sigma B_{i,\tau}'}$$

s.t.

$$\widetilde{A}_0(1,j) = 0 \quad \forall j > 1$$

[19] In using a maximum forecast error variance approach, Barsky and Sims (2011) build on earlier work by Faust (1998), Uhlig (2004), and Francis et al. (2014).

$$\gamma(1,1) = 0$$

$$\gamma'\gamma = 1$$

where the first two constraints ensure that the anticipated external shock has no contemporaneous effect on the Federal Funds rate, and the third restriction narrows the solution space to the one of possible orthogonalizations of the reduced form, by preserving the orthonormality of the rotation matrix D. By imposing that γ must be a unit vector, the second column γ of matrix D is identified. The second step consists in recovering the domestic monetary policy shock of small open economy k. This shock can be identified by making use of the condition that the matrix D must be orthonormal, i.e. $DD' = D'D = I$. More specifically, letting $\gamma* = [0\ \gamma_1\ \gamma_2]$ where $\gamma_2 = -\sqrt{1-\gamma_1^2}$, then one can express D as:[20]

$$D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \gamma_1 & \gamma_2 \\ 0 & -\gamma_2 & \gamma_1 \end{bmatrix} \tag{1.4}$$

where the first column ensures that the unanticipated external shock ($\varepsilon_t^{\star}$) is the orthogonal innovation to the Federal Funds rate, the second column results from the maximization problem above and therefore captures the whole set of shocks that induce future movements in the Federal Funds rate ($\varepsilon_t^{\star\star}$), and the third column identifies the monetary policy shock

[20] The negative sign in front of γ_2 is just a normalization. Specifically, to preserve the orthonormality of D, one needs the 2×2 lower right submatrix of D to have either opposite diagonal elements or opposite off-diagonal elements.

of country k (ε_t^{mp}) that may affect both the nominal exchange rate and the policy controlled interest rate, while it has no contemporaneous or future impact on the external variable ($r^\star$).[21] Last, *for any* orthogonalization $\widetilde{A}_0$ of residuals u_t which satisfies the first constraint of the above maximization problem, the structural shocks can be recovered from the relation

$$u_t = \widetilde{A}_0 D \varepsilon_t. \tag{1.5}$$

where D is the rotation matrix previously identified, and $\varepsilon_t \equiv [\varepsilon_t^\star \;\; \varepsilon_t^{\star\star} \;\; \varepsilon_t^{mp}]'$.

1.2.4 Comparison between identification schemes

What is the relation between the shocks identified using a recursive identification and the ones identified with the proposed alternative? By combining equations (1.1) and (1.5) one can show that

$$\widetilde{\varepsilon}_t^{mp} = \gamma_1 \varepsilon_t^{\star\star} + \gamma_2 \varepsilon_t^{mp} \tag{1.6}$$

where $\widetilde{\varepsilon}_t^{mp}$ is the domestic monetary policy shock under a recursive identification, whereas $\varepsilon_t^{\star\star}$ and ε_t^{mp} are the anticipated external shock and the domestic monetary policy shock identified under the proposed alternative identification, respectively. Equation (1.6) implies the following. If the restrictions underlying a recursive identification were correct, both identification strategies would recover exactly the same set of shocks. In that case, the estimated value of γ_1 would be zero. However, if anticipated external shocks exist and

[21] By construction this condition is subjected to the maximization above, therefore results can still deliver that a monetary policy shock has some, but likely insignificant, future effects on the Federal Funds rate.

spill over into the small open economy (that is, if estimated $\gamma_1 \neq 0$), standard recursive identification schemes fail to correctly recover the true monetary policy shock.

The empirical evidence reported below is the result of estimating a set of VAR models using the approach just described. We begin by showing the results for the effect of a country-specific monetary policy shock (Section 1.3), and then present the impulse responses associated with an anticipated external shock (Section 1.4). We will also document the conditional behavior of ex ante excess returns (Section 1.5). We frame our main results in the form of impulse response functions (IRFs). Bias-corrected bootstrapped 90% confidence intervals are based on 1000 replications (see Kilian, 1998).

1.3 Effects of a domestic monetary policy shock

Table 1.1 reports the results for the identified exchange rate response to monetary policy innovations in our sample of countries. To determine whether a domestic monetary contraction results in a currency appreciation, we follow Hnatkovska, Lahiri and Vegh (2016) and report whether the response of the exchange rate after an interest rate shock is negative on impact, at the end of the first month, and at the end of the first quarter. Based on country-by-country VARs we compute the share of developing countries that have experienced appreciations of their exchange rates following a 1% positive shock to the interest rate, under the two identification schemes discussed here. For each country we also record the size of the (log) exchange rate response and report the median of these responses. Table 1.1 clearly indicates that accounting for anticipated movements in the external variable (the

Federal Funds rate) matters: under the identification strategy proposed in this paper, the share of economies that see their exchange rate appreciating after a positive interest rate shock is much larger than under the recursive identification scheme. This occurs on impact (70% of developing countries relative to 27%), one month after (70% relative to 27%) and three months after (67% relative to 30%). In terms of median magnitudes of the exchange rate responses, we find that the exchange rate appreciates by 0.76% on impact, 1.18% after one month and 1.33% after three months, in developing and emerging countries. For industrial countries, the share of countries that experience an appreciation is around 90% and the median magnitudes of appreciation are around 2.5%. All these figures are statistically significant. Overall, we argue that accounting for spillovers of external shocks goes a long way in resolving the puzzling exchange rate responses found in the literature.

Figure 1.2 reports the exchange rate responses to a 1% policy-induced increase in the interest rate obtained by applying our econometric framework to each of the countries in our sample. Panel 1.2a features the IRFs for the non-US G7 economies, while Panel 1.2b reports the IRFs for the six largest developing and emerging economies in our sample.

We find that the exchange rate response puzzle does not emerge under our proposed identification strategy. In fact, in nearly all countries, regardless of their development status, a policy-induced interest rate hike leads to a significant impact appreciation of the local currency, with the only exception being Brazil, whose exchange rate response resembles the one obtained under a recursive identification scheme.[22] The quantitative impact response

[22] In overviewing the recent experience of Brazil, Blanchard (2004) attributes the apparent exchange rate depreciation after an interest rate increase to a higher probability of default on government debt induced by

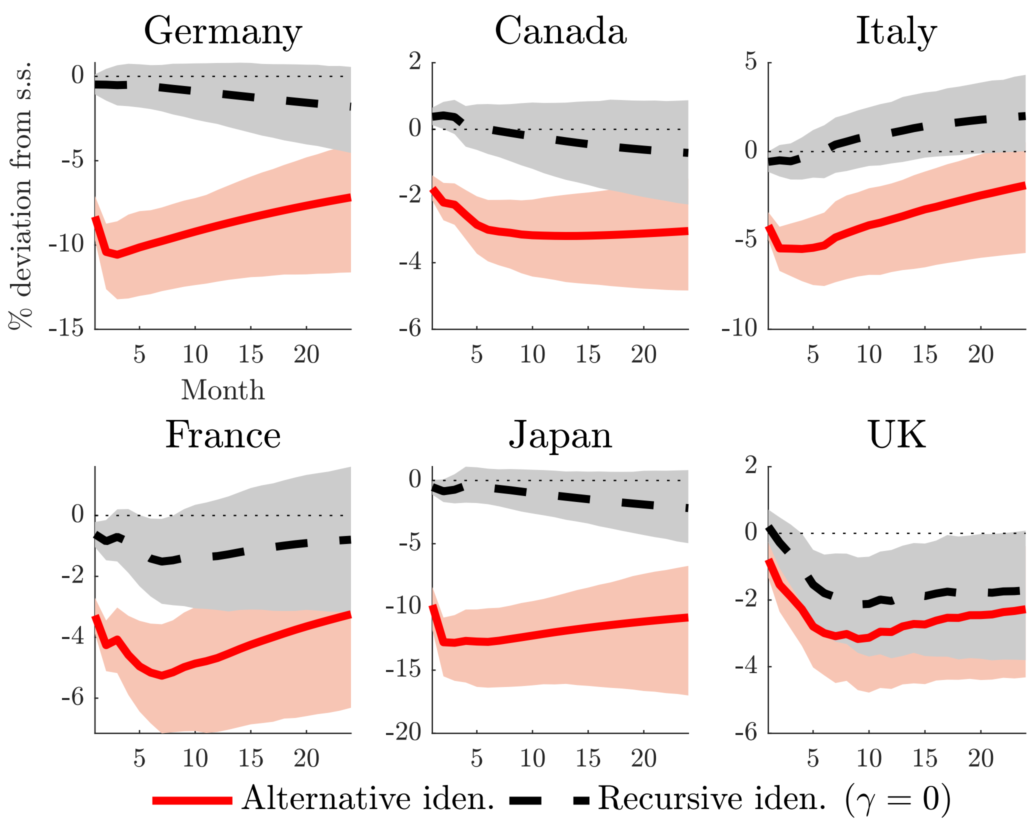
	Recursive iden. ($\gamma_1 = 0$)			Alternative iden.		
	Impact	1 month	3 months	Impact	1 month	3 months
Industrial countries						
Share with appreciation	78%	83%	78%	91%	91%	91%
Median of s_t response	-0.31	-0.48	-0.39	-2.40	-2.93	-2.82
	(0.10)	(0.15)	(0.19)	(0.33)	(0.42)	(0.44)
Developing countries						
Share with appreciation	27%	27%	30%	70%	70%	67%
Median of s_t response	0.25	0.30	0.21	-0.76	-1.18	-1.33
	(0.08)	(0.12)	(0.12)	(0.22)	(0.33)	(0.34)

Table 1.1: Empirical exchange rate response to a 1% contractionary monetary policy shock
Notes: The table reports the fraction of countries that experience an appreciation of their exchange rate following a 1 percent positive shock to the domestic policy rate, and the size of the (log) exchange rate responses. Standard deviation of the median responses are reported in parentheses. The impulse responses on the impact, first month, and first quarter (three months) are reported based on a country-by-country VAR analysis.

of the nominal exchange rate to a 1% policy-induced increase in the interest rate differs notably from country to country. In fact, the impact appreciation of the exchange rate that we observe ranges from around 1% to around 10%. These numbers are largely in line with other estimates from the VAR literature on advanced economies.

Figure 1.2 also reports the IRFs that result from a monetary policy shock identified through a recursive scheme. This identification scheme produces the exchange rate response puzzle: the impact response of most developing countries' exchange rate to a monetary contraction is positive (i.e., a nominal depreciation), unlike for most industrial countries whose impact response is either negative (i.e., a nominal appreciation) or statistically insignificant,

higher interest rates.



(a) Industrial countries

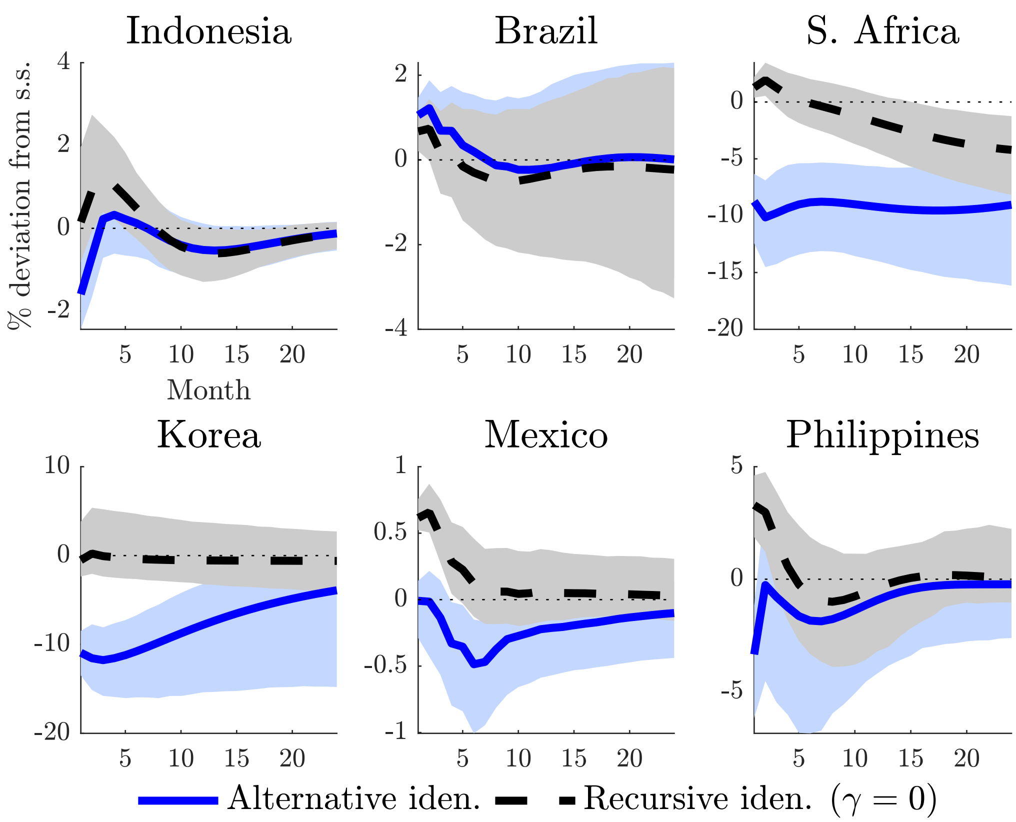
Figure 1.2: Empirical exchange rate response to a 1% contractionary monetary policy shock

Note: The red solid lines are the estimated IRFs to our identified 1% interest rate increase from the baseline three-variable VAR. The blue dashed lines are the estimated IRFs to 1% interest rate increase from the baseline three-variable VAR identified using a recursive scheme. The shaded areas are the 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR.

with the only exception being Canada.[23]

Alternative identification in multivariate VAR with domestic output and inflation. We ask whether the exchange rate response to monetary policy innovation is robust

[23] The impulse responses that we obtain under the Cholesky identification scheme are slightly different from those reported in Hnatkovska, Lahiri and Vegh (2016) because they run a bivariate VAR with interest rate differential and bilateral exchange rate. Instead, we separate the two interest rates and run a trivariate VAR.



(b) Developing and emerging countries

Figure 1.2: Empirical exchange rate response to a 1% contractionary monetary policy shock

Note: The red solid lines are the estimated IRFs to our identified 1% interest rate increase from the baseline three-variable VAR. The blue dashed lines are the estimated IRFs to 1% interest rate increase from the baseline three-variable VAR identified using a recursive scheme. The shaded areas are the 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR.

to controlling for the dynamics of domestic output and inflation. To do so, we extend our baseline VAR to include industrial production (in log changes) and CPI inflation. To extend our identification of domestic monetary policy shocks we need to impose additional identification restrictions on the effect of various domestic shocks. We thus follow Eichenbaum and Evans (1995) in assuming that innovations in output and inflation affect interest rates and exchange rates contemporaneously, while domestic monetary policy shocks influence these variable with a (one month) lag (See Appendix A.2.6 for further details). Our results, reported in Figure A.2.3 in Appendix A.2.6, reveal that accounting for the influence of output and inflation does not substantially affect the response of the exchange rate to a domestic monetary policy innovation. Besides, a monetary contraction brings about a (short-lived) decline in output, in line with standard macro models. The inflation response to a monetary contractions appears insignificant in developing countries, while it generates the so-called price puzzle in industrial economies, as often observed in the related literature.

1.4 Effects of an anticipated external shock

What are the effects of anticipated external shocks? What explains a country's exposure to their spillover effects? In this section, we present a set of empirical results that aim at answering these questions.

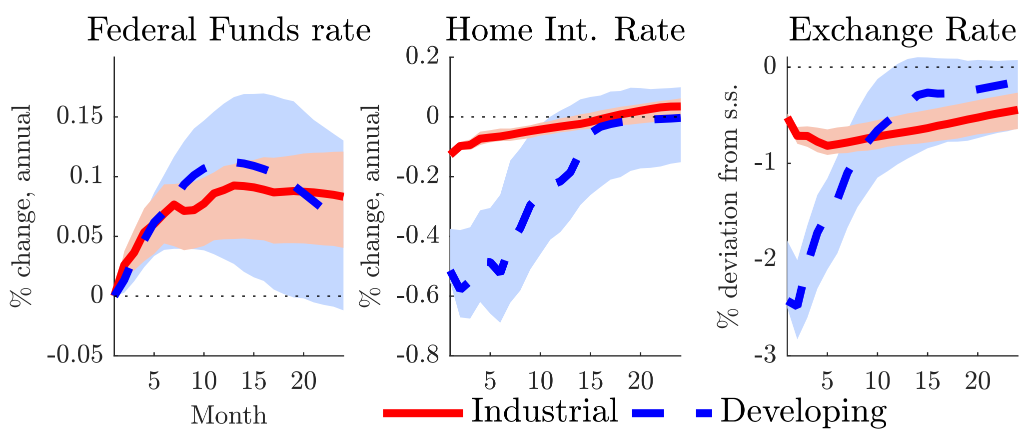


Figure 1.3: Empirical IRFs to an anticipated external shock
Note: The lines denote median IRFs by group of countries with corresponding 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR.

Figure 1.3 shows the effects of a shock that signals a future increase in the Federal Funds rate, by reporting the median IRFs to an anticipated external shock by country group, while Appendix A.2.4 reports the same IRFs country by country.[24,25] An external shock that anticipates a future increase in the Federal Funds rate induces a nominal appreciation and interest rate decline, the comovement that was originally attributed to domestic monetary policy shocks. Further inspection reveals that the quantitative effect of these international spillovers is larger in developing countries relative to industrial ones; in fact, developing countries' median exchange rates and interest rates are considerably more sensitive to external shocks that signal a similar future increase in the Federal Funds rate. More specifically, a shock that leads the Federal Funds rate to increase by about 10 basis points in the following ten months leads to a 0.5% and 2% median impact exchange rate appreciations in industrial and developing countries, respectively, as well as a 15 basis points impact interest rate decline in industrial countries, compared to a 60 basis points impact interest rate decline in developing countries. At this point, recall that a recursive identification scheme would confound these correlations for the monetary policy innovation (see Section 1.2.4). Since these two shocks induce opposite correlations between exchange rate and interest rate a recursive identification scheme is subject to producing estimates of the exchange rate channel of monetary policy that feature an opposite sign relative to those implied by our proposed identification. Given our empirical results, this outcome should ob-

[24] In Figure 1.3, IRFs are normalized to obtain a similar-size expected increase in the Federal Funds rate.
[25] In Appendix A.2.2, we show that the informational content in the baseline VAR is sufficient to identify the anticipated external shock.

tain for countries that are more susceptible to anticipated external shocks. A forecast error variance decomposition of our VAR (Figure A.2.1 in Appendix A.2) reveals that anticipated external shocks explain a substantial fraction of policy interest rates and nominal exchange rates in small open economies, and this fraction is larger (around 50%) in developing and emerging economies.[26] In other words, anticipated external shocks largely account for the positive *unconditional* covariance between interest rates and exchange rates that appears in developing and emerging economies, and has been documented by Hnatkovska, Lahiri and Vegh (2016). It is natural at this point to ask what anticipated external shocks capture.

1.4.1 The nature of anticipated external shocks: global risk aversion

We study the effects of anticipated external shocks on a larger set of external variables, including U.S. industrial production, inflation in the U.S. Consumer Price Index (CPI), and the Chicago Board Options Exchange Volatility Index (VIX), a forward-looking measure of uncertainty and risk aversion. Figure 1.4 shows that an anticipated external shock that signals a future increase in the Federal Funds rate is associated to a hump-shaped increase in U.S. industrial production, temporarily higher U.S. CPI inflation, and a temporary decline in the VIX. These statistically significant comovements are typical of demand-driven business-cycle fluctuations, associated with movements in risk aversion, and do *not* appear to be driven by U.S. monetary policy shocks.

In this sense, our estimated anticipated external shocks are largely associated to move-

[26] In addition to the results emphasized in the text, Figure A.2.1 shows that the anticipated external shocks shocks explains around 15% of the variation of the Federal Funds rate at a two-year horizon.

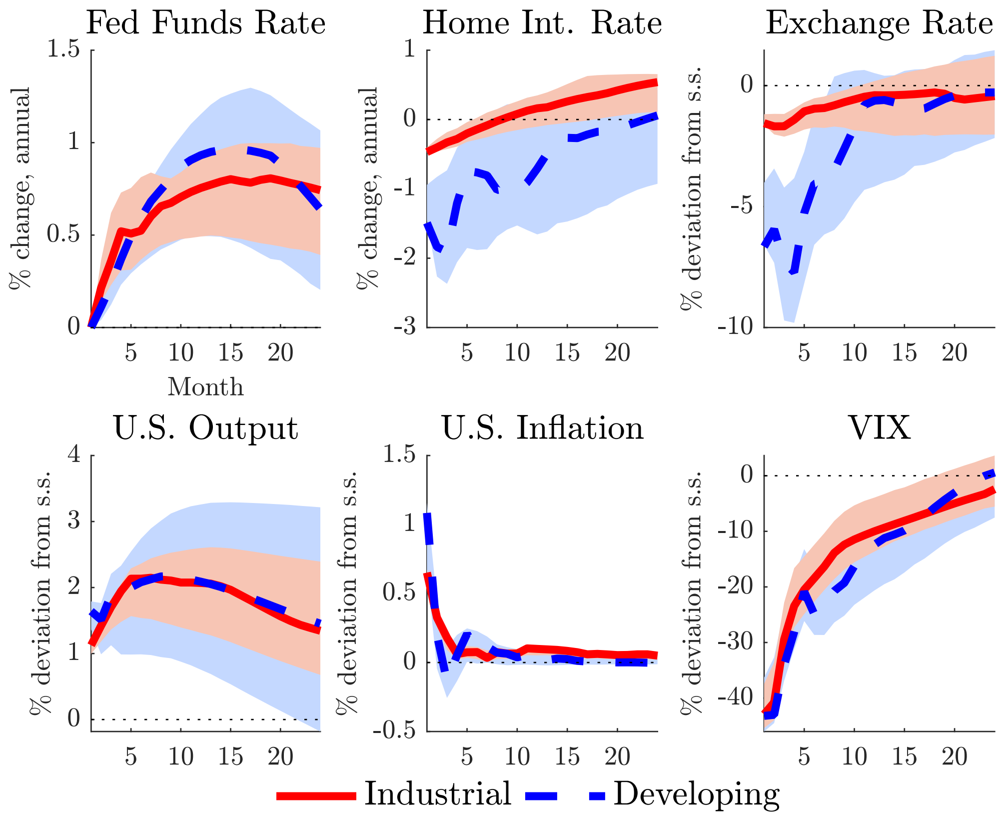


Figure 1.4: Empirical IRFs to an anticipated external shock (Other external variables)
Note: This figure features the estimated IRFs to the anticipated external shock on a set of external variables from a four-variable VAR with the three baseline variables and U.S. industrial production, U.S. CPI inflation, or the VIX ordered fourth. The solid line and the dashed lines denote median IRFs of industrial and developing countries respectively. The shaded areas are the corresponding 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR.

ments in global risk aversion, echoing numerous findings in the literature. In fact, researchers similarly found that global movements in the VIX are associated with considerable financial spillovers into small open economies' asset prices (e.g. Bruno and Shin, 2015, and Rey, 2015) and currency excess returns (e.g. Lustig, Roussanov and Verdelhan, 2011 and Della Corte, Riddiough and Sarno, 2016).

1.4.2 The role of a country's net foreign asset position

Does a country's net foreign asset position matter for its exposure to external shocks? A natural measure of exposure to external shocks is the fraction of the forecast error variance of a country's exchange rate that is explained by the external shock.[27] In Figure 1.5, we show that countries with a higher ratio of net foreign liabilities to GDP tend to be more exposed to external shocks. The line of best fit is significant in both the baseline and extended samples, and are equal to -1.66 and -0.56, respectively. We take this as evidence that a country's net foreign asset position is a key determinant of exposure to external disturbances. We also note that while a country's net foreign asset position is correlated with its development status, there are several exceptions that suggest that the level of development may not be the key factor that determines exposure to external shocks.[28] In Section 3.2, we introduce a model in which the net foreign asset position is the relevant measure of international financial market exposure for the small open economy's currency risk. In the model, countries with higher net foreign debt are more exposed to exogenous changes in the risk bearing capacity of financial markets.

[27] Other measures, such that the exchange rate response to external shocks lead to similar results.

[28] In fact, an advanced country like Canada is both a net debtor and highly exposed to external shock, while the opposite is true for developing countries such as South Africa and Korea.

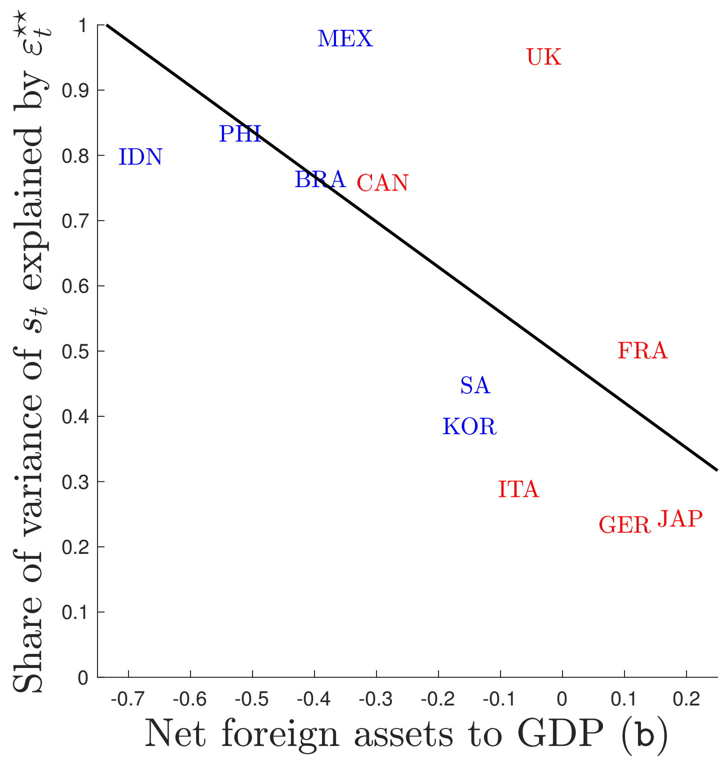


Figure 1.5: Net foreign assets and the exposure to external shocks
Note: Data on annual net foreign asset position to GDP are from the updated and extended version of dataset constructed by Lane and Milesi-Ferretti (2007). "Net foreign assets to GDP" is a country's average over its sample period.

1.5 Ex ante excess returns and the exchange rate response to domestic and external shocks

Do different shocks generate different dynamic patterns of currency excess returns? The interest in this question is threefold. First, the literature on monetary policy and exchange rates in industrial economies often finds UIP deviations conditional on monetary policy shocks (e.g., Eichenbaum and Evans, 1995, and Faust and Rogers, 2003). Second, a strand of the international finance literature is concerned with the sources of currency excess returns, and a decomposition of these across structural shock appears desirable. Third, a satisfactory explanation of the above empirical findings should be consistent with all aspects of exchange rates, interest rate differentials, and excess returns (see Section 3.2).

1.5.1 Conditional UIP deviations

We begin by constructing series of excess returns conditional on domestic monetary policy shocks (ε^{mp}) and anticipated external shocks ($\varepsilon^{\star\star}$), and analyze their dynamic behavior. In line with the relevant literature, the ex ante excess return on the domestic bond held from period t to period $t+1$, inclusive of the expected currency return, is defined as:

$$\mathrm{E}_t\, \hat{x}_{t+1} \equiv \hat{r}_t - \hat{r}_t^{\star} - \mathrm{E}_t\, \Delta \hat{s}_{t+1} \tag{1.7}$$

where hatted variables denote series generated by our VAR, and E_t is the expectation operator conditional on time-t information. Non-zero ex ante excess returns point to violation of so-called UIP. In fact, under UIP the exchange rate would be expected to depreciate at a rate that equals the interest rate differential.

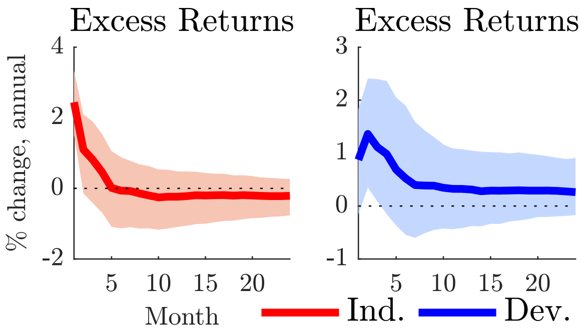
Figure 1.6 reports the dynamic responses of one-year ahead ex ante excess returns to our identified shocks.[29] The dynamic response of excess returns appears different across shocks. After a contractionary domestic monetary policy innovation, excess returns are relatively small and short lived. In the wake of a 1% impact increase in the domestic policy rate,

[29] That is, we report the returns from an investment of one year maturity on the domestic bond. This is given by: $\mathrm{E}_t\, \hat{x}_{t+12} \equiv \hat{r}_t - \hat{r}_t^{\star} - \mathrm{E}_t\, \Delta \hat{s}_{t+12}$, where interest rates are annualized.

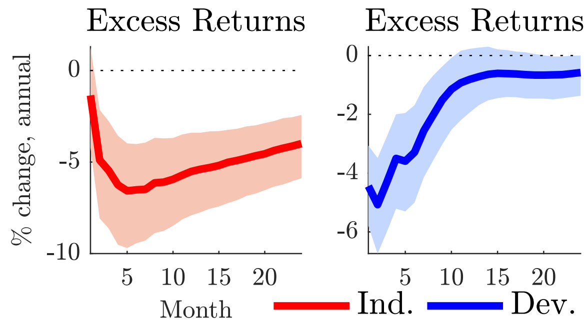
the domestic currency experiences about a 2% (1%) impact increase in excess returns in industrial (developing) economies. After 2-3 months, the response of excess returns is largely insignificant for both set of countries. To the contrary, after anticipated external shocks, excess returns are relatively large and persistent. In the wake of an anticipated external shock (re-scaled to cause a 1% impact decline in the domestic policy rate), the domestic currency experiences significant declines in excess returns for more than two years (about 1 year) in industrial countries (developing countries). Also, peak responses of excess returns tend to be significantly larger than what we observe conditional on domestic monetary policy shocks. Figure A.2.4 in Appendix A.2 documents that these patterns hold also in country-specific VARs, with few exceptions. Overall, we find robust evidence in favor of large deviations from UIP due to anticipated external shocks, but not in response to domestic monetary policy shocks. In light of these results, we note that our identified monetary policy shocks are generally associated with a mild degree of delayed overshooting (see Appendix A.2.5 for a discussion).

1.5.2 UIP deviations and the exchange rate response to shocks

What do the above patterns of excess returns imply for the exchange rate response to shocks? We follow Engel (2016) and iterate Eq. (1.7) forward to measure the relation



(a) Domestic monetary policy shock



(b) Anticipated external shock

Figure 1.6: The empirical response of currency excess returns
Note: The figure shows the response of one-year ahead ex ante excess returns to domestic monetary policy shocks and anticipated external shocks. IRFs are re-scaled so that they reflect responses to a 1% impact change in the interest rate differential.

between ex ante excess returns and the level of the exchange rate. This implies:[30]

$$\hat{s}_t = \hat{s}_t^{UIP} + \mathrm{E}_t \sum_{j=0}^{\infty} \hat{x}_{t+j+1} \tag{1.8}$$

where $\hat{s}_t^{UIP} \equiv -\mathrm{E}_t \sum_{j=0}^{\infty} \left(\hat{r}_{t+j} - \hat{r}^{\star}_{t+j}\right)$ is the exchange rate level consistent with UIP. Besides this component, the current level of the exchange rate is influenced by the infinite sum of ex ante excess returns. As the above empirical results generally point to differences in the conditional covariance between the exchange rate level and the interest rate differential across structural shocks, we note that Eq. (1.8) implies:[31]

$$\mathrm{Cov}(\hat{s}_t, \hat{r}_t - \hat{r}_t^{\star}) = \mathrm{Cov}(\hat{s}_t^{UIP}, \hat{r}_t - \hat{r}_t^{\star}) + \mathrm{Cov}(\mathrm{E}_t \sum_{j=0}^{\infty} \hat{x}_{t+j+1}, \hat{r}_t - \hat{r}_t^{\star})$$

[30] In deriving Eq. (1.8) we impose that $\lim_{j\to\infty} \hat{s}_{t+j} = 0$, consistent with the observation that our VAR generates stationary time series.
[31] More specifically, $\mathrm{Cov}(\hat{s}_t, \hat{r}_t - \hat{r}_t^{\star} \mid \varepsilon^{\star\star}) > 0$, while $\mathrm{Cov}(\hat{s}_t, \hat{r}_t - \hat{r}_t^{\star} \mid \varepsilon^{mp}) < 0$

	Ant. ext. shocks		Dom. mon. pol. shocks	
Regression equation	β_S in (1.9)	β_M in (1.10)	β_S in (1.9)	β_M in (1.10)
Industrial countries				
Germany	44.2	-21.2	-125.0	-96.9
	(0.88)	(0.62)	(1.38)	(1.42)
Canada	92.2	13.2	-53.3	-53.0
	(4.10)	(1.44)	(2.21)	(1.04)
Italy	46.9	-3.9	-49.9	-19.1
	(4.40)	(0.53)	(1.83)	(0.45)
France	55.1	-14.2	-81.4	-23.3
	(1.58)	(0.39)	(3.04)	(0.56)
Japan	64.3	-34.7	-204.4	-177.4
	(0.87)	(0.67)	(8.20)	(5.36)
UK	169.6	-13.6	-36.2	-17.3
	(1.92)	(0.32)	(1.33)	(0.35)
Developing countries				
Indonesia	13.1	-4.4	-3.0	-8.3
	(1.44)	(0.44)	(0.71)	(0.62)
Brazil	39.9	-0.8	9.0	-7.5
	(5.57)	(1.19)	(0.81)	(0.48)
South Africa	30.3	-12.2	-93.4	-27.5
	(1.95)	(0.74)	(6.84)	(1.48)
Korea	66.2	-22.0	-25.6	-41.9
	(2.95)	(1.18)	(5.32)	(4.79)
Mexico	13.0	-3.0	-2.7	-8.5
	(0.38)	(0.27)	(0.69)	(0.72)
Philippines	49.7	0.5	-5.9	-5.9
	(2.68)	(0.55)	(3.65)	(1.64)

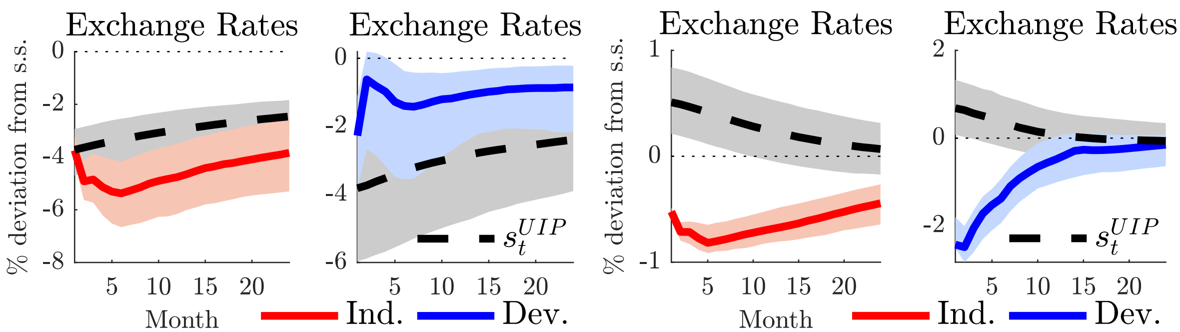
Table 1.2: Contribution of ex ante excess returns to exchange rate level

Notes: The four columns report the estimated values of coefficients β_S and β_M in regression equations (1.9) and (1.10), respectively. Standard errors are reported in parentheses. These regressions are run on VAR generated data in which only anticipated external shocks are active (Columns 1 and 2) and VAR generated data in which only domestic monetary policy shocks are active (Columns 3 and 4). Standard errors are reported in parentheses.

This equation represents a useful decomposition of the covariance between exchange rates and interest rate differentials. In fact, it allows us to assess to what extent this covariance differs from the one implied by the path of the UIP-consistent exchange rate. To do so, we construct series for the three variables in Eq. (1.8) conditional on one shock at a time, and run the following two regressions:[32]

$$\hat{s}_t = \alpha_S + \beta_S(\hat{r}_t - \hat{r}_t^{\star}) + u_{S,t} \tag{1.9}$$

$$\hat{s}_t^{UIP} = \alpha_M + \beta_M(\hat{r}_t - \hat{r}_t^{\star}) + u_{M,t} \tag{1.10}$$



(a) Domestic monetary policy shock **(b)** Anticipated external shock

Figure 1.7: Exchange rates and their UIP component
Note: The figure shows the exchange rate response to anticipated external shocks and domestic monetary policy shocks. It also reports the response of the UIP component of the exchange rate, s^{UIP}, according to the decomposition in Eq. (1.8).

Coefficient β_S in Eq. (1.9) captures the elasticity of the level of the exchange rate to the interest rate differential, while coefficient β_M in Eq. (1.10) captures the elasticity of the infinite sum of ex ante excess returns to the interest rate differential. The contribution of ex ante excess returns to the dynamics of the level of the exchange rate are captured by the difference between β_M and β_S. Table 1.2 reports the estimated values of these coefficients conditional on our identified shocks. The main observation is that under anticipated external shocks the covariance between the level of the exchange rate and the interest rate differential

[32] When constructing infinite sums of VAR generated series, we use a sufficiently high truncation horizon.

appears to mostly reflect the component associated with cumulative excess returns. That is, under external shocks estimated β_S are significantly positive, while estimated β_M are significantly negative.[33] This implies that the cumulative sum of excess returns covaries positively with the interest rate differential and is pivotal in determining the response of the exchange rate to anticipated external shocks. The behavior of the level of the exchange rate under domestic monetary policy shocks is instead largely determined by its UIP component. In fact, except for Brazil, the level of the exchange rate is qualitatively consistent with UIP.

Figure 1.7 depicts the median response of actual exchange rate ($\hat{s}_t$) and its component consistent with UIP ($\hat{s}_t^{UIP}$) to both external and domestic shocks. This evidence reinforces the results presented so far: the bulk of the exchange rate response to external shocks is accounted for by the behavior of excess returns, while the exchange rate response to monetary policy shocks is not significantly different from the one predicted by UIP.[34]

1.6 Interpreting our empirical results

To provide a rationale for our empirical findings, we build a two-country small open economy dynamic general equilibrium model. After a brief introduction of the model environment, we present a summary of the equilibrium conditions in log-linear form and highlight the key mechanisms (Section 1.6.1), while Appendix A.3 contains the full derivation of the model. Then, we use the model to interpret the empirical IRFs and the observed differences across

[33] Canada and Philippines are the only exceptions

[34] Median responses for developing countries indicate that the exchange rate tends to react more weakly to a domestic monetary policy innovation than the response implied by UIP.

groups of countries (Sections 1.6.3 and 1.6.4). We conclude this section by analyzing the performance of different VAR identification schemes on data simulated from the theoretical model (Section 1.6.5).

1.6.1 Environment and equilibrium equations

The core of the baseline framework belongs to the international macroeconomic tradition initiated by Obstfeld and Rogoff (1995). It consists of a two-country dynamic general equilibrium model with incomplete asset markets, monopolistically competitive producers and sticky prices, introduced along the lines of Calvo (1983). As prices are set in the producer's currency, the model features complete exchange rate pass-through. Asset markets are incomplete in that agents can only trade nominal riskless bonds denominated in Home and Foreign currency.[35] We assume that foreign-currency-denominated bonds are only traded in the foreign economy. We depart from the standard small open economy DSGE model by assuming that all international transactions are intermediated by financial traders who are averse to large risky positions (Jeanne and Rose, 2002, Gabaix and Maggiori, 2015, Itskhoki and Mukhin, 2017). Last, we follow De Paoli (2009) in characterizing the small open economy by taking the limit of the home economy size to zero. The limit is taken after having derived the equilibrium conditions for the two-country model. Thus, the two countries, Home and Foreign, represent the small open economy and the large economy, respectively. The foreign economy represents the United States, and is interpreted as the

[35] The implications of this model would obtain in a model in which agents in the small open economy borrow in foreign currency, but hedge their currency mismatch resorting to international financial markets.

center of the international financial system.

Households and the financial sector

We consider two countries, Home (H) and Foreign (F). The world economy is populated with a continuum of agents of unit mass, where the population in the segment $[0, n)$ belongs to country H and the population in the segment $(n, 1]$ belongs to country F.

Domestic economy. The domestic economy is populated by a representative household whose preferences are given by

$$\mathrm{E}_t \sum_{j=0}^{\infty} \beta^j \left[\frac{C_t^{1-\omega}}{1-\omega} - \frac{N_t^{1+\eta}}{1+\eta} \right] \tag{1.11}$$

where N_t denotes hours worked, E_t is the expectation operator conditional on time-t information, and C_t is a composite consumption index defined by

$$C_t \equiv \left[(\nu)^{\frac{1}{\theta}} (C_{H,t})^{\frac{\theta-1}{\theta}} + (1-\nu)^{\frac{1}{\theta}} (C_{F,t})^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

where $C_{H,t}$ is an index of consumption of domestic goods given by the CES function

$$C_{H,t} \equiv \left[\left(\frac{1}{n} \right)^{\frac{1}{\iota}} \int_0^n C_{H,t}(i)^{\frac{\iota-1}{\iota}} \mathrm{d}i \right]^{\frac{\iota}{\iota-1}}$$

where $i \in [0, 1]$ denotes the good variety. $C_{F,t}$ is an index of goods imported from the foreign country given by an analogous CES function:

$$C_{F,t} \equiv \left[\left(\frac{1}{1-n} \right)^{\frac{1}{\iota}} \int_n^1 C_{F,t}(i)^{\frac{\iota-1}{\iota}} \mathrm{d}i \right]^{\frac{\iota}{\iota-1}}$$

Parameter $\iota > 1$ denotes the elasticity of substitution between varieties (produced within any given country). Parameter $1-\nu \in [0,1]$ governs the home consumers' preferences for foreign goods, and is a function of the relative size of the foreign economy, $1-n$, and of the degree of openness, λ, namely $1-\nu = (1-n)\lambda$. Parameter $\theta > 0$ measures the substitutability between domestic and foreign goods, from the viewpoint of the domestic consumer.

Domestic households can trade only a one-period nominal bond, which is denominated in domestic currency. The domestic household's flow budget constraint is given by

$$\frac{B_{t+1}}{R_t} + P_t C_t = W_t N_t + B_t \tag{1.12}$$

where B_{t+1} denotes the nominal balance of home bonds, R_t is the nominal interest rate on the home bond, P_t is the price index of the composite consumption good C_t, and W_t is the nominal wage rate. The problem of the domestic household consists in maximizing its utility (Eq. 1.11) subject to the budget constraint (Eq. 1.12). The first-order conditions of this problem are standard and therefore relegated to Appendix A.3.

Foreign economy. The foreign economy is populated by a continuum of households.

At the beginning of each period, all members of a household are identical and share the household's assets. During the period, the members are separated from each other, and each member receives a shock that determines the role of the member in the period. A member will be a trader with probability m_t, and a worker with probability $1-m_t$. These shocks are i.i.d. among the members. We follow Cavallino (Forthcoming) in assuming that the share of members that operate as traders in the international financial market is proportional to the output of the home economy (that is, $m_t = \mu n P^{\star}_{H,t} Y_t$). This assumption entails that traders devote a larger part of their balance sheets to bonds issued by larger economies, and allows us to map the model to data on the ratio of net foreign assets to GDP. The members' preferences are aggregated and represented by the following utility function of the household:

$$\mathrm{E}_t \sum_{j=0}^{\infty} \beta^{\star j} \left[m_t \mathcal{U}(\widetilde{C}^{\star}_t) + (1-m_t)\mathcal{U}(C^{\star}_t, N^{\star}_t) \right]$$

where

$$\mathcal{U}(\widetilde{C}^{\star}_t) \equiv \frac{\left(\widetilde{C}^{\star}_t\right)^{1-\omega^{\star}_t}}{1-\omega^{\star}_t} \tag{1.13}$$

and

$$\mathcal{U}(C^{\star}_t, N^{\star}_t) \equiv \frac{(C^{\star}_t)^{1-\omega^{\star}_t}}{1-\omega^{\star}_t} - \frac{(N^{\star}_t)^{1+\eta}}{1+\eta}$$

Here, $\widetilde{C}^{\star}_t$ is the consumption of traders, $C^{\star}_t$ is the consumption of workers, and $\omega^{\star}_t$ governs the degree of (relative) risk aversion of both household's members. We assume that foreign households' risk aversion is time varying. In particular, $\omega^{\star}_t = \omega^{\star} \exp(\xi_t)$ and its time-varying component evolves according to the following autoregressive process:

$$\xi_t = \rho_\xi \xi_{t-1} + \varepsilon_{\xi,t} \tag{1.14}$$

where $\varepsilon_{\xi,t}$ are i.i.d. disturbances drawn from a Normal distribution with mean zero and standard deviation $\sigma_{\xi^\star}$. The problem of the worker-member of the foreign household is standard, and analogous to the one of the domestic household. Her intertemporal budget constraint reads

$$\frac{B^\star_{t+1}}{R^\star_t} + P^\star_t C^\star_t = B^\star_t + W^\star_t N^\star_t - \frac{m_t}{1-m_t} T^\star$$

where $m_t T^\star$ is an intrahousehold transfer that accrues to the trader-members of the households, while the other foreign variables are interpreted analogously to their domestic counterparts. The first-order conditions of this problem are standard and therefore relegated to Appendix A.3.

Traders on the foreign exchange market. Traders of measure m_t are the only agents who can trade bonds internationally. Since traders are part of the foreign household, the foreign economy is interpreted as the center of the international financial system. Traders collectively take a zero-capital position $\widetilde{D}_{t+1}$ in home-currency bonds and short $\widetilde{D}^\star_{t+1} = -\widetilde{D}_{t+1}/S_t$ foreign-currency bonds, or vice versa. Here, S_t is the nominal exchange rate, defined to be the price of the foreign currency unit (units of home currency per unit of foreign currency), as in the empirical section. The exchange rate is relevant for the balance sheet of international traders because each economy offers a bond in its own currency. A one U.S.-dollar position generates a U.S.-dollar return of $\widetilde{R}_{t+1} = R_t^\star - R_t \frac{S_t}{S_{t+1}}$. The problem of each individual trader consists in choosing a position $d_{t+1}^\star$ to maximize (1.13) subject to the budget constraint $P_t^\star \widetilde{C}_t^\star = T^\star + \widetilde{R}_{t+1} d_{t+1}^\star$, where $T^\star$ denotes an intrahousehold transfer that ensures that the trader's consumption is always non-negative. In Appendix A.3.1 we show that the individual trader's problem is approximately equivalent to maximizing a mean-variance utility of returns. The resulting demand for home-currency bonds by the household traders is then

$$\widetilde{D}_{t+1}^\star = \frac{m_t}{\omega_t^\star} \frac{\mathrm{E}_t\, \widetilde{R}_{t+1}}{\mathrm{Var}_t(\widetilde{R}_{t+1})} \Rightarrow \frac{\widetilde{D}_{t+1}}{S_t} = -\frac{m_t}{\omega_t^\star} \frac{\mathrm{E}_t\, \widetilde{R}_{t+1}}{\mathrm{Var}_t(\widetilde{R}_{t+1})} \tag{1.15}$$

The financial market clears when the interest rates R_t and $R_t^\star$ are such that $B_{t+1} + D_{t+1} = 0$ and $B_{t+1}^\star + D_{t+1}^\star = 0$, which in particular implies that in equilibrium the net foreign asset position of home equals net foreign liabilities of foreign, $nB_{t+1} = -(1-n)B_{t+1}^\star S_t$, in aggregate per-capita terms.[36] Thus, Eq. 1.15 becomes:

$$-\frac{B_{t+1}}{P_{H,t} Y_t} = \frac{\mu}{\omega_t^\star} \frac{\mathrm{E}_t \left(R_t \frac{S_t}{S_{t+1}} - R_t^\star \right)}{\mathrm{Var}_t(\widetilde{R}_{t+1})} \tag{1.16}$$

Finally, we follow De Paoli (2009) in taking the limit for $n \to 0$ to portray our small open economy. This implies that economic developments in the large economy affect the small open economy, but the reverse is not true. Under this assumption, the mass of household-

[36] Here, $nD_t = \widetilde{D}_t$ and $(1-n)D_t^\star = \widetilde{D}_t^\star$.

traders $m_t \to 0$, $\forall t$. As a result, traders influence the model's behavioral equations only through their pricing of the exchange rate. The resulting profits from their trading activity are infinitesimally small from the standpoint of the foreign economy, and don't affect the household's budget constraint.

We solve the model by log-linearization around a steady state with a non-zero net foreign asset position, and use $\mathtt{b} \equiv {}^{B}/_{P_H Y}$ to denote the steady-state net foreign asset position relative to GDP of the Home economy. Using the international bond market clearing condition, the linearized version of the traders' bond demand (Eq. 1.16) reads

$$\chi \left(-\mathtt{b}\xi_t - b_{t+1}\right) \approx r_t - r_t^\star - \mathrm{E}_t\, \Delta s_{t+1} \tag{1.17}$$

where $\chi \equiv \frac{\sigma_s^2}{\mu/\omega^\star}$ governs traders' risk bearing capacity in steady state.[37] Eq. (1.17) is the exchange rate determination equation of our model economy. The standard UIP condition obtains as a special case when the risk-bearing capacity of traders $\chi = 0$. In turn, this is true if traders are risk neutral ($\omega^\star = 0$), the size of the financial sector $\mu \to \infty$, or the exchange rate is non-stochastic ($\sigma_s^2 \equiv \mathrm{Var}_t(\Delta s_{t+1}) = 0$).[38] If $\chi > 0$, the model economy features two sources of UIP deviations - exogenous changes in global risk aversion ξ_t and endogenous movements in the net foreign asset position to GDP, b_{t+1}, where $b_{t+1} \equiv {}^{B_{t+1}}/_{P_{H,t} Y_t} - {}^{B}/_{P_H Y}$. As emphasized by Gabaix and Maggiori (2015), an equilibrium imbalance that requires traders to be long in a currency generates an increase in the expected return

[37] For illustration purposes, Eq. (1.17) is an approximation in that it ignores the terms arising because of steady-state UIP deviations.

[38] The variance of the innovation to the nominal exchange rate, σ_s^2, is endogenously determined.

of this currency. In this simple model, a country's imbalance is directly related to its net foreign asset position. A negative net foreign asset position requires traders to be long in that country's currency and therefore requires an increased expected return of this currency. The level of expected excess returns required by traders is proportional to their risk bearing capacity. Thus, changes in global risk aversion affect the degree of expected returns demanded by traders in equilibrium. In our linearized model, changes in risk bearing capacity have a *direct* effect on exchange rate determination if a country's steady-state net foreign asset position is non-zero. If the steady-state net foreign asset position of a country is negative, traders are long in that country's currency. In this case, higher global risk aversion requires higher expected returns on this currency to provide the incentive for risk-averse traders to keep absorbing the imbalance. The opposite reasoning holds for countries that are net creditors in steady state. This mechanism is consistent with Della Corte, Riddiough and Sarno's (2016) evidence that net-debtor countries experience a significantly larger currency appreciation during periods of low global risk aversion (proxied by the VIX) than net-creditor countries.

Firms

Each country features a continuum of firms that produce output under a constant-returns-to-scale production function. The economy-wide production functions are thus $Y_t = AN_t$ and $Y_t^\star = AN_t^\star$ for the domestic and foreign goods, respectively.

We assume that each producer sets its price in her own currency. In this case the law of one price holds. Under these conditions, $P_{H,t} = S_t P^{\star}_{H,t}$ and $P_{F,t} = S_t P^{\star}_{F,t}$ for each t. However, the home bias specification leads to deviations from purchasing power parity; that is, $P_t \neq S_t P^{\star}_t$. Prices follow a partial adjustment rule as in Calvo (1983). Producers of differentiated goods know the form of their individual demand functions, and maximize profits taking overall market prices as given. In each period a fraction, $\alpha \in [0, 1)$, of randomly chosen producers is not allowed to change the nominal price of the goods they produce. The remaining fraction of firms, given by $1 - \alpha$, chooses prices optimally by maximizing the expected discounted value of profits.

Monetary authorities

In each country, the monetary authority is assumed to follow a Taylor (1993)-type rule with interest-rate smoothing:

$$r^{\star}_t = \rho_r r^{\star}_{t-1} + (1-\rho_r)\phi\pi^{\star}_t + \varepsilon_{r^{\star},t} \qquad r_t = \rho_r r_{t-1} + (1-\rho_r)\phi\pi_t + \varepsilon_{r,t}$$

where $\varepsilon_{r^{\star},t}$ and $\varepsilon_{r,t}$ are i.i.d. disturbances drawn from a Normal distribution with mean zero and standard deviations $\sigma_{r^{\star}}$, and σ_r, respectively.[39] In line with central banks' practices, we assume that they target a measure of consumer price (CPI) inflation.[40]

[39] Monetary authorities are assumed to target a zero inflation steady state.

[40] The results presented below hold if the domestic central bank is assumed to respond also to variations in the nominal exchange rate, as in Monacelli (2004), in line with the evidence of "fear of floating" reported by Calvo and Reinhart (2002).

1.6.2 Steady state, calibration, and log-linear equations

In our model, the size of traders' balance sheet depends on risk perceptions. To account for risk in the computation of the model, we follow Coeurdacier, Rey and Winant (2011) in deriving the "risky" steady state, defined as a steady state in which agents expect future risk and the realization of shocks is zero at the current date. The risky steady state differs from the non-stochastic state only by second order terms related to variances and covariances of the endogenous variables. These second moments pin down the size of traders' long-run balance sheet. To analyze model dynamics, we then look at a first order log-linear approximation around the risky steady state. Importantly, we allow the steady-state net foreign assets, $\mathtt{b}$, to be non-zero, in line with the evidence for most developing and emerging economies. To do so, we allow a difference in the home and foreign countries' discount factors, that is $\beta < \beta^\star$, and thus different steady-state returns on their bonds.

Our benchmark target for $\mathtt{b}$ is a net foreign asset position relative to (annual) GDP of around -35%, the average value in our sample of the largest developing and emerging economies.[41] Our model is calibrated to a monthly frequency. We set $\beta^\star = 0.9967$ which implies a steady state annual interest rate of about 4%, and $\eta = 1$ which implies a unit Frisch elasticity. Our calibration of the Calvo parameter ($\alpha = 0.9167$) implies an average duration of price contracts of one year. We set the consumption share of imports $\lambda = 0.4$, and the trade elasticity $\theta = 1$. The Taylor-rule coefficient on consumer price inflation, ϕ, equals 1.5, while the parameter that governs the degree of interest rate smoothing, ρ_r, equals

[41] Data on annual net foreign asset position to GDP are from the updated and extended version of dataset constructed by Lane and Milesi-Ferretti (2007)

0.947, in line with typically estimated values in the DSGE literature. We set $\rho_\xi = 0.90$, and we follow Itskhoki and Mukhin (2017) and set the parameter that governs the risk-bearing capacity of the financial sector, $\chi = 0.01$.[42]

We choose the variances of our model's structural shocks so that the model reproduces three empirical moments in our sample of countries: the unconditional variance of nominal exchange rate changes, the observed unconditional deviation from UIP and the unconditional contemporaneous correlation between the exchange rate and the interest rate differential.[43]

We report below the model's log-linear equilibrium conditions, evaluated at the risky steady state.[44] The equilibrium conditions that govern economic dynamics in the large (Foreign) economy read:

$$\omega^\star \, \mathrm{E}_t \, \Delta c^\star_{t+1} + \omega^\star \, \mathrm{E}_t \, \Delta \xi_{t+1} = r^\star_t - \mathrm{E}_t \, \pi^\star_{t+1} \tag{1.18a}$$

$$\pi^\star_t = \beta^\star \, \mathrm{E}_t \, \pi^\star_{t+1} + \kappa^\star((\eta + \omega^\star)c^\star_t + \omega^\star \xi_t) \tag{1.18b}$$

$$r^\star_t = \rho r^\star_{t-1} + (1-\rho)\phi \pi^\star_t + \varepsilon_{r^\star,t} \tag{1.18c}$$

where $\kappa^\star = \frac{(1-\beta^\star\alpha^\star)(1-\alpha^\star)}{\alpha^\star}$. Given the exogenous processes, the economic dynamics in the large economy are fully described by the consumption Euler equation (Eq. 1.18a), the New

[42] Without loss of generality we normalize the steady state so that $\ln(C^\star) = 1$.

[43] Our model therefore matches $\mathrm{Var}(\Delta s_t)$, α_1 in $\Delta s_{t+1} = \alpha_0 + \alpha_1(i_t - i^\star_t)$, and β_1 in $\Delta s_t = \beta_0 + \beta_1 \Delta(i_t - i^\star_t)$.

[44] All variables are expressed as log deviations from their steady state, except for net foreign assets to GDP (b_t), which is expressed as changes from its steady state. Also, $\widetilde{\beta} \equiv {}^1\!/\!_{\mathrm{R}}$.

Keynesian Phillips curve (Eq. 1.18b), and the monetary policy rule (Eq. 1.18c). Both Eqs. (1.18a) and (1.18b) are influenced by shocks to foreign households' (global) risk aversion, which act in effect as "demand" shocks.

Domestic variables are determined according to the following system of log-linear equations:

$$\omega \, \mathrm{E}_t \, \Delta c_{t+1} = r_t - \mathrm{E}_t \, \pi_{t+1} \tag{1.19a}$$

$$\pi_{H,t} = \beta \, \mathrm{E}_t \, \pi_{H,t+1} + \kappa(\omega c_t + \eta y_t + \lambda(1-\lambda)^{-1} q_t) \tag{1.19b}$$

$$r_t = \rho r_{t-1} + (1-\rho)\phi \pi_t + \varepsilon_{r,t} \tag{1.19c}$$

$$\pi_t = (1-\lambda)\pi_{H,t} + \lambda(\Delta s_t + \pi_t^\star) \tag{1.19d}$$

$$y_t = \theta\lambda(1-\lambda)^{-1} q_t + (1-\lambda)(1+\mathtt{b}-\widetilde{\beta}\mathtt{b})c_t + \left[1-(1-\lambda)(1+\mathtt{b}-\widetilde{\beta}\mathtt{b})\right](c_t^\star + \theta q_t) \tag{1.19e}$$

$$\widetilde{\beta}\,(b_{t+1} - \mathtt{b} r_t) - b_t + \mathtt{b}\,(\pi_{H,t} + \Delta y_t) = (1+\mathtt{b}-\widetilde{\beta}\mathtt{b})\left(y_t - c_t - \lambda(1-\lambda)^{-1} q_t\right) \tag{1.19f}$$

$$\Delta s_t = \Delta q_t - \pi_t^\star + \pi_t \tag{1.19g}$$

where $\kappa = \frac{(1-\beta\alpha)(1-\alpha)}{\alpha}$. Besides an analogous Euler equation (Eq. 1.19a), a PPI Phillips curve (Eq. 1.19b), and a CPI-inflation targeting rule (Eq. 1.19c), the small economy is influenced by global dynamics since it is effectively open to goods and asset trade. For this reason, marginal costs in Eq. (1.19b) and aggregate demand for domestically produced goods (Eq. 1.19e) depend upon the terms of trade (which can be expressed as a function of the real exchange rate, q_t). Also, aggregate demand for the Home goods depends on

Foreign consumption, in proportion to the degree of trade openness, λ. Importantly, complete exchange rate pass-through implies that nominal exchange rate fluctuations directly translate into changes in Home CPI (Eq. 1.19d), exactly because import prices are denominated in the (Foreign) producer's currency, and these adjust sluggishly. The exchange rate is determined according to Eq. (1.17), described above. In this environment, there are three structural shocks: Home and Foreign monetary policy innovations ($\varepsilon_{r,t}$ and $\varepsilon_{r^\star,t}$), and shocks to global risk aversion ($\varepsilon_{\xi,t}$).

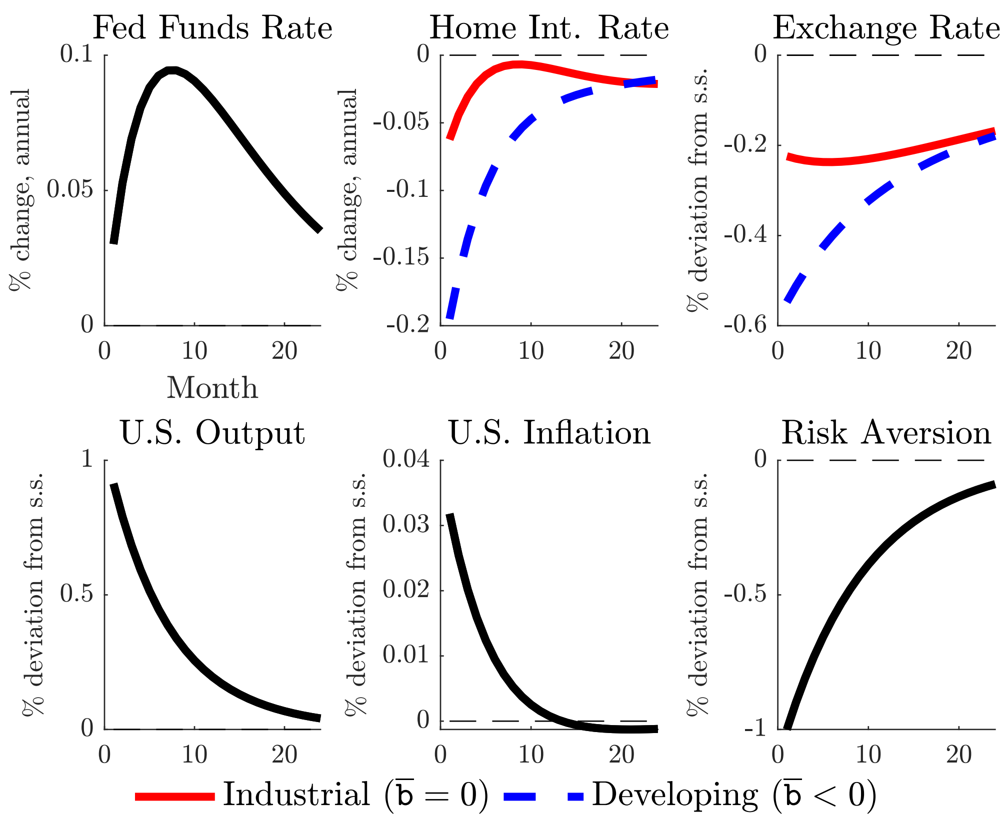


Figure 1.8: Theoretical IRFs to a temporary reduction in global risk aversion
Note: The impulse is an unanticipated 1% reduction in the foreign (large) economy's degree of risk aversion.

1.6.3 Equilibrium dynamics following a shock to global risk aversion

Figure 1.8 depicts the IRFs to a temporary reduction in global risk aversion. In the Foreign economy, a temporary lower level of risk aversion induces households to increase current consumption, while firms' faced with higher demand raise their prices. The Foreign central bank responds to the ensuing inflationary pressures by gradually raising the nominal interest rate, as implied by its aversion to inflation and desire for interest rate smoothing. In the Foreign economy (U.S.), a decline in global risk aversion is therefore associated with rising consumption (output), higher inflation, and a rising nominal interest rate.

This shock spills over into the domestic economy through its effect on the exchange rate and external demand for Home goods. *Ceteris paribus*, a decline in global risk aversion induces the financial sector to require lower excess returns on the domestic currency, thereby causing an instantaneous appreciation of the nominal exchange rate (Eq. 1.17). This effect is reinforced by higher external demand for domestic goods, which improves its net foreign asset to GDP position and reduces the degree to which international financial traders are exposed to Home currency risk. These forces dominate over the nominal depreciation implied by the interest rate differential. In fact, the exchange rate response to this shock is largely driven by the behavior of excess returns, as depicted in Figure 1.10b. The nominal appreciation of the small economy's exchange rate brings about a contemporaneous fall in import prices (in local currency) which puts downward pressure on domestic CPI inflation (see Eq. 1.19d). In our calibrated model, the deflationary forces implied by lower (domestic-currency) prices of imported goods dominate in determining the short-run dynamics of CPI inflation.[45] As a result, the Home central bank cuts the nominal interest rate. Thus, this shock acts as a favorable supply shock in the small economy imposing a procyclical response of an inflation-targeting monetary authority. The unconditional procyclicality of monetary policy in developing and emerging countries is a widely documented fact (e.g., see recent survey by Frankel (2010)).

The role of a country's net foreign asset position

In Figure 1.8, we also report the IRFs of a small open economy that features a zero steady-state net foreign asset position ($\mathtt{b} = 0$) to represent the response of the typical advanced economy.[46] In this economy, changes in global risk aversion have no direct influence on the small open economy's exchange rate, only an indirect one through the equilibrium interest rate differential and net foreign asset position. As a result, an economy with $\mathtt{b} = 0$ is less exposed to global risk aversion shocks relative to a net-debtor economy ($\mathtt{b} < 0$). In this sense, our model is capable of reproducing the empirical IRFs in Figure 1.4 by attributing the cross-country differences in responses to their observed differences in net foreign asset positions. This mechanism is consistent with the evidence in Della Corte, Riddiough and Sarno (2016): higher global risk aversion (proxied by the VIX) is associated with a stronger dollar, especially against currencies of net debtor countries.

Furthermore, we show that the model's predictions on exposure and net foreign asset

[45] The domestic component of CPI inflation reflects two opposing forces: higher product demand and adverse expenditure-switching effect due to worsening of the terms of trade.

[46] The average long-run net foreign asset position to GDP of the largest advanced small open economies in our sample is in fact around zero.

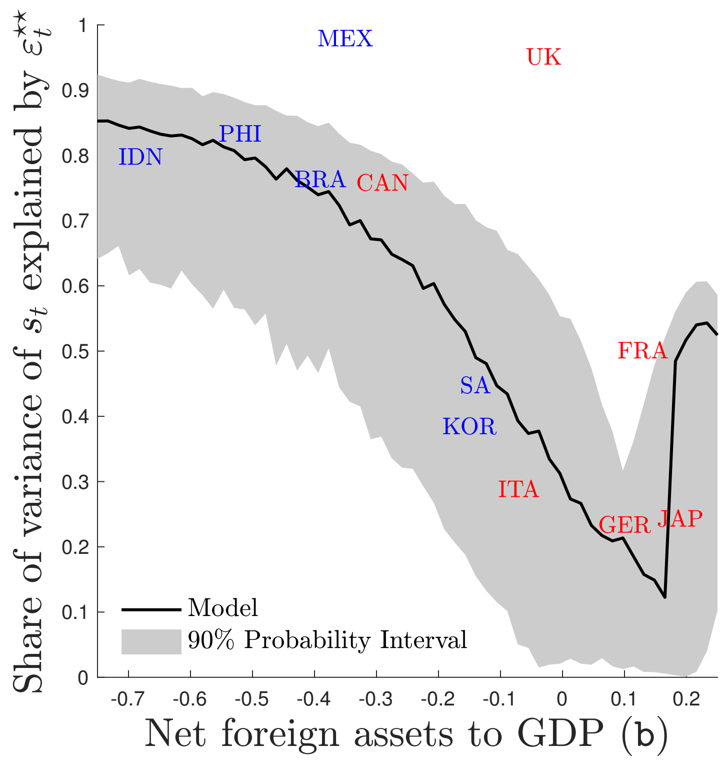


Figure 1.9: Net foreign assets and the exposure to external shocks
The black line denotes the fraction of forecast error variance of s_t that is explained by $\varepsilon_t^{\star}\star$ as we let b take values that we observe in our baseline sample.

positions align well with the cross-country evidence, as illustrated in Figure 1.9.[47] Note that for

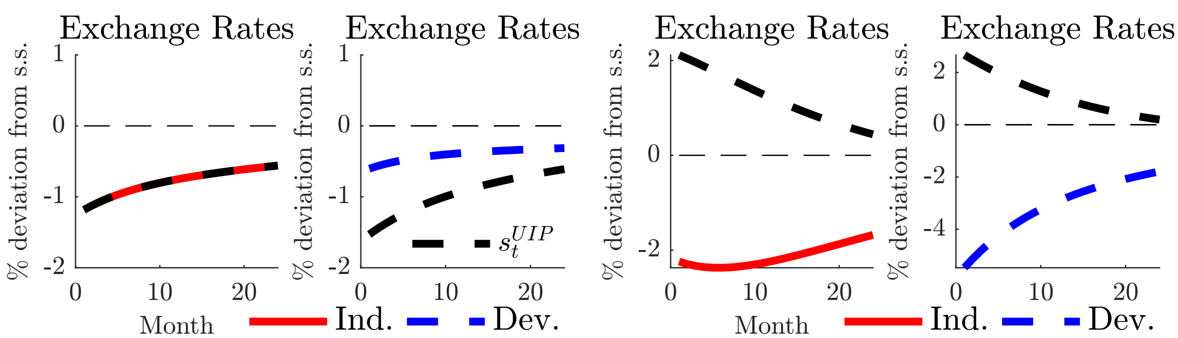
1.6.4 Conditional UIP deviations in the theoretical model

Figure 1.10a depicts the theoretical IRFs of a country's exchange rate to a temporary 1% increase in the domestic interest rate. UIP suggests that an unexpected tightening in monetary policy leads to an immediate appreciation of the currency and a future depreciation. Our model reproduces this pattern qualitatively, but also features deviations from the UIP-

[47] Mexico and especially UK represent the only exception.

consistent exchange rate due to the dynamics of the ratio of net foreign assets to GDP. In the baseline model ($\mathtt{b} < 0$), the equilibrium decline in Home GDP increases the real value of the ratio NFA/GDP. This induces traders to requires higher expected returns on the home currency (see Eq. 1.17). The outcome is an equilibrium exchange rate appreciation that is smaller than what is implied by UIP, in line with the evidence for developing and emerging economies in Figure 1.7a. In industrial economies (model with $\mathtt{b} = 0$), this mechanism is largely muted and the exchange rate response is generally in line with its UIP counterpart.

Figure 1.10b depicts the theoretical IRFs of a country's exchange rate to a temporary decline in global risk aversion. The model reproduces the evidence in Figure 1.7b. Deviations from UIP account for the response of the exchange rate to external shocks.

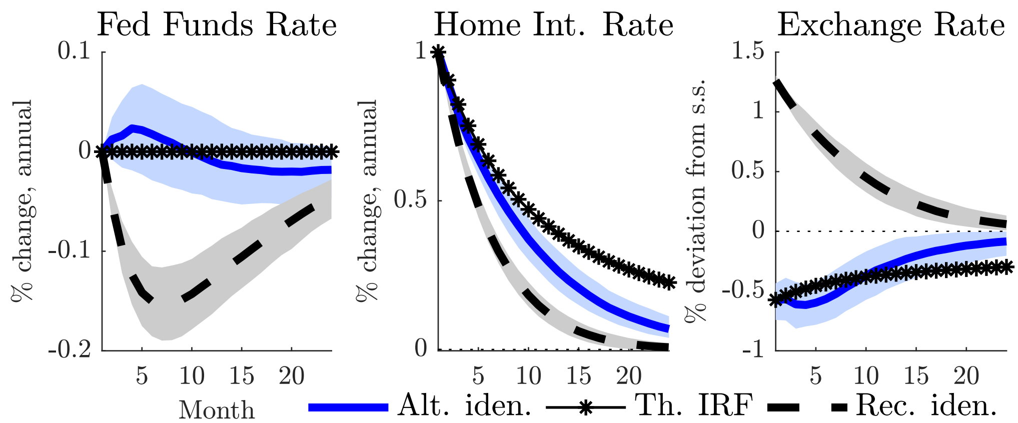


(a) Domestic monetary policy shock **(b)** Global risk aversion shock

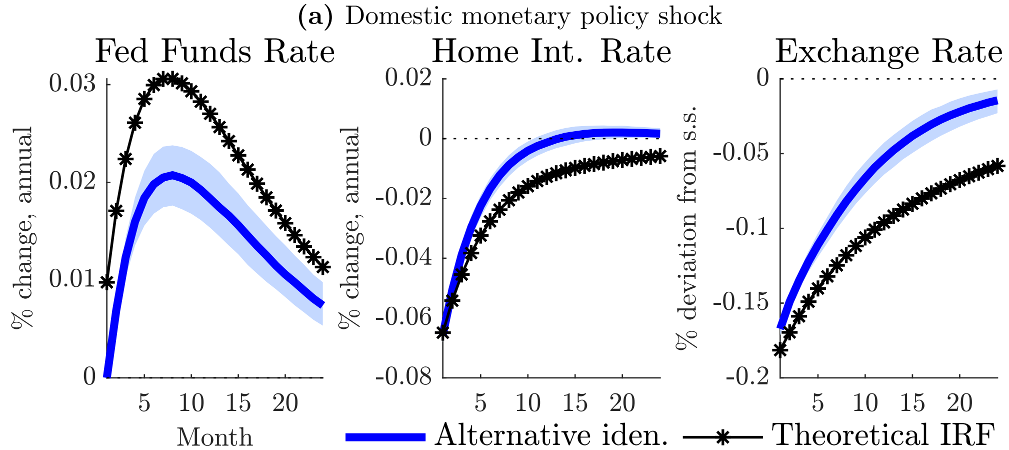
Figure 1.10: Theoretical exchange rate responses and their UIP component
Note: The figure shows the exchange rate response to domestic monetary policy shocks and global risk aversion shocks. It also reports the response of the UIP component of the exchange rate, s^{UIP}, according to the decomposition in Eq. (1.8). The responses of industrial and developing countries reflect a different calibration of the steady-state NFA/GDP, $\mathtt{b}$ (See text)

1.6.5 Examining the performance of identification schemes

To examine the performance of our empirical approach, a three-variable system identical to the baseline empirical specification is estimated on model generated data. We show that our empirical approach performs quite well, whereas a recursive VAR scheme reproduces the exchange rate puzzle. Figure 1.11 indicates that the IRFs stemming from our alternative



(a) Domestic monetary policy shock



(b) Anticipated external shock and model's response to global risk aversion shock

Figure 1.11: Model and Monte Carlo estimated IRFs: three-variable VAR
Note: The black starred line shows the theoretical IRF from the model presented in Section 3.2. The solid lines are the average estimated IRF from a Monte Carlo simulation with 45 repetitions (countries) and 150 observations per repetition. The shaded areas are the 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR. In Panel (a) both the recursive identification scheme ($\gamma_1 = 0$) and our proposed alternative are estimated on model-generated data.

VAR-based identification scheme are generally in line with the theoretical ones. In fact, the identified domestic monetary policy shock maps closely into the Home monetary policy shock in the model, while the anticipated external shock maps into the global risk aversion shock, providing support for our identification scheme. Figure 1.11a also presents the IRFs implied by a recursive identification. The recursive VAR fails to correctly capture the exchange rate response to a monetary policy innovation. In contrast to the theoretical response, the recursive VAR suggests that a policy-induced interest rate increase triggers a nominal depreciation. In addition, the monetary policy shock series identified under the recursive scheme predicts significant changes in the Federal Funds rate, as in Figure 1.1. This happens exactly because the recursive scheme conflates the independent variation in the domestic interest rates and its endogenous response to changes in global risk aversion.

This evidence, together with that reported in Table 1.3, indicates that our model explains the reasons behind the emergence of the exchange rate puzzle.

1.6.6 Discussion

While the model explains a large fraction of the exchange rate response to domestic and external shocks, it should not be interpreted as a comprehensive descriptor of the economics at play. First, the only source of cross-country heterogeneity in our model are differences in net foreign asset positions. While this is consistent with the evidence reported in Figures 1.5 and 1.9, other mechanisms can reasonably give rise to heterogeneous responses to external shocks. Some examples are differences in countries' size (Hassan, 2013), commodity

	Recursive iden.		Alternative iden.	
	Data	Model	Data	Model
Industrial countries				
Share with appreciation	78%	100%	91%	98%
Median of s_t response	-0.31	-0.56	-2.40	-2.80
	(0.10)	(0.03)	(0.33)	(0.12)
Developing countries				
Share with appreciation	28%	0%	69%	67%
Median of s_t response	0.24	1.24	-0.69	-0.75
	(0.07)	(0.03)	(0.18)	(0.10)

Table 1.3: Empirical exchange rate response to a 1% contractionary monetary policy shock
Notes: The table reports the fraction of countries that experience an impact appreciation of their exchange rate following a 1 percent positive shock to the domestic policy rate, and the size of the (log) exchange rate impact responses. Standard deviation of the median responses are reported in parentheses.

intensity (Ready, Roussanov and Ward, 2017), monetary policy rules (Backus et al., 2010), or financial development (Maggiori, 2017). Investigating whether these mechanisms are capable of explaining part (if any) of the differences in estimated exchange rate responses is beyond the scope of our paper. Second, we model the domestic central bank as a strict CPI-inflation targeter, consistent with stated practices of central banks in nearly all small open economies in our sample. That said, departures from this monetary rule can reasonably provide complementary explanations for the observed behavior of monetary policy. In the context of our model, raising the domestic nominal rate in response to a nominal depreciation can be the optimal policy because it avoids excessive depreciation and the associated adverse wealth effects.

1.7 Conclusions

This paper concerns the sources of exchange rate fluctuations in small open economies. We began by documenting that international spillovers of external shocks present a challenge to identifying shocks in small open economies, particularly in common VAR settings. In fact, traditional identification strategies in VARs lead one to confound monetary policy innovations with the central banks' endogenous response to external shocks. We showed that these shortcomings are at the heart of recent estimates of puzzling exchange rate responses to monetary policy. We find that international spillovers (operating through exchange rates) are larger for net-debtor economies, the countries for which the exchange rate response puzzle has primarily been documented. In other words, exchange rate fluctuations in these economies are predominantly explained by external disturbances, and not by domestic monetary policy. In particular, we documented that *one* external shock drives a large fraction of exchange rate fluctuations in the typical small open economy, especially in net debtor countries. This shock is associated with large movements in global risk aversion, and is the primary driver of cyclical deviations from UIP.

We illustrated that these empirical correlations can be interpreted as the equilibrium of a two-country small-open economy in which a country's net foreign asset position and global risk aversion play a key role in exchange rate determination. The model we introduced can reproduce all our findings: the evidence on the determinants of countries' exposure to international spillovers, the evidence on the origins of UIP deviations, and the emergence and resolution of the exchange rate response puzzle. In future work, we plan to explore the policy implications of this model. In particular, the model suggests that countries with different NFA positions should differently benefit from pegging their currency to the U.S. dollar. In fact, under fixed exchange rates UIP deviations are nil (due to the absence of currency risk), while UIP deviations are larger and costlier for net debtor countries. This observation points to the importance of designing models featuring data-consistent microfoundations of UIP deviations.[48]

[48] Besides, our model points to one potential limitation of dynamic stochastic models of emerging markets primarily driven by shocks to the external interest rate. While the present paper suggests that external shocks are indeed prominent, it also suggests that changes in the external interest rate can have different effects on exchange rates depending on whether they reflect U.S. monetary policy shocks or the systematic response of the Federal Funds rate to other types of shocks.

Chapter 2

Should Central Banks Target Investment Prices?

2.1 Introduction

Since the 1990s, many central banks around the world have adopted inflation targeting as a means of conducting monetary policy and communicating policy commitments to the public. Over the years, most countries that have adopted an inflation targeting policy state their target in terms of an index of consumer price inflation.[1] In a recent blog post, Bernanke (2015) writes, "In practice, the FOMC has long been clear that its preferred measure of

[1] The Federal Reserve targets inflation in the core PCE index, but also closely tracks CPI and PPI inflation. The primary objective of the European Central Bank is price stability and its Governing Council has announced that "price stability is defined as a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%." For comprehensive overviews of the inflation indices targeted by monetary authorities around the world, see Svensson and Leiderman (1995), Bernanke et al. (1999), and Svensson (2010).

inflation is the rate of change in consumer prices, as reflected specifically in the deflator for personal consumption expenditures (PCE).” Later in the same post, he continues, “Frankly, I don’t think there is much of a case for ... using the GDP deflator to measure inflation rather than using overall or core PCE inflation.”

Bernanke summarizes the current state of central bank thinking about the appropriate price index to target. We believe this consensus should be examined using economic models. We present a model showing that targeting consumer prices alone leads to significantly larger welfare losses than targeting an index of consumer and investment-goods prices. We find that optimal policy in our model puts much *more* weight on investment price inflation than does the GDP deflator. In fact, even though investment is only about 20 percent of GDP, in our calibrated model the central bank should put approximately equal weight on stabilizing consumer and investment price inflation.

Why do we come to these conclusions? As we will show, targeting consumer prices alone would be innocuous if either investment-goods prices were fully flexible, or if shocks to consumer and investment demand were symmetric.[2] The evidence does not appear to support either hypothesis. Our model has nominal rigidities for both consumption and investment goods and imperfectly correlated shocks to the two sectors, which reproduces key features of the data. Optimal policy in the model requires that the central bank should target investment prices. Furthermore, in the model omitting the investment price from the

[2] To our knowledge, nearly all New Keynesian models with investment make one of these two assumptions, the exceptions being Basu, Fernald and Liu (2014) and Ikeda (2015). For example, models based on Smets and Wouters (2007) implicitly assume a flexible relative price for investment goods, since an investment-specific technology improvement in their framework immediately increases the number of investment goods that can be obtained by foregoing one consumption good.

central bank's target leads to substantial welfare losses.

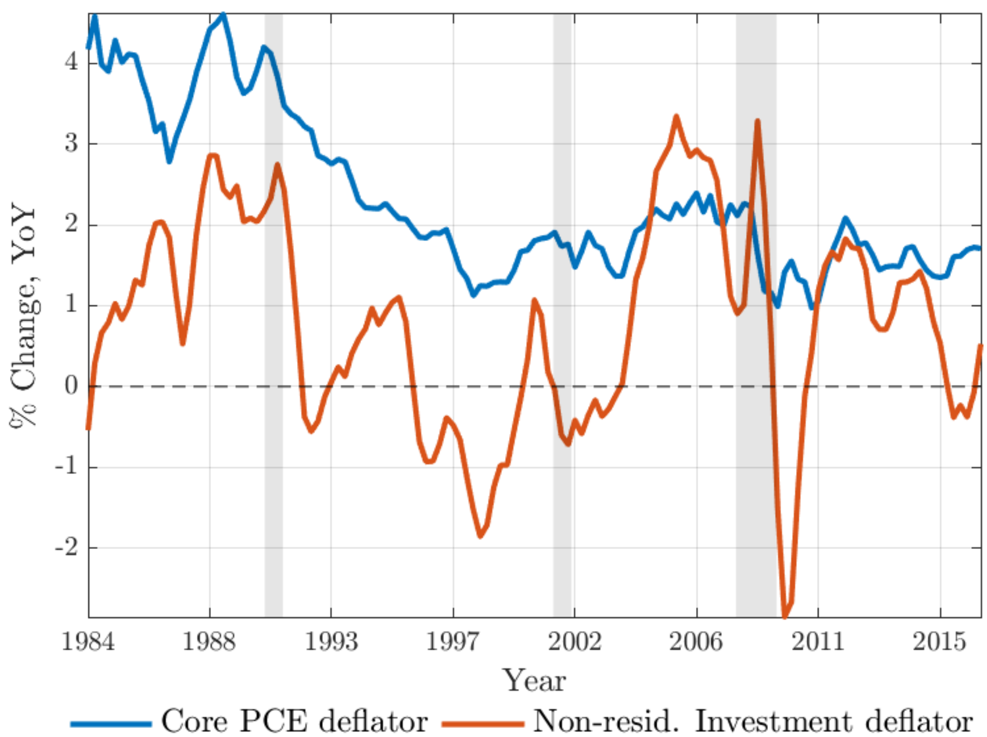


Figure 2.1: Inflation dynamics of consumer and investment-good prices
Note: "CORE PCE deflator" corresponds to the price deflator for Personal Consumption Expenditures less Food and Energy, while "Non-resid. Investment Deflator" is the price deflator for Fixed Investment less Residential Investment, as provided by the U.S. Bureau of Economic Analysis. Both variables are seasonally adjusted.

The intuition for the quantitative result stems from an important economic difference between consumption and investment goods: the intertemporal elasticity of substitution (IES) is likely to be much higher for investment than for consumption demand. The IES for consumption is relatively small – typical estimates put it around 0.5. Under a plausible set of assumptions, the IES in investment is nearly infinite.[3] Thus, small changes in the own real interest rate for investment due to expected changes in the price of investment goods have huge effects on investment demand, which is not the case for consumption. This difference in the IES leads to the asymmetry in optimal policy: in order to keep outcomes close to the social optimum, it is more important to avoid fluctuations in investment price inflation than in consumption price inflation.

Since our argument depends on the existence of nominal rigidities in the prices of investment goods, it is fair to ask whether the evidence supports this assumption. Available microeconomic evidence points to substantial price stickiness in several categories of investment goods: for example, Nakamura and Steinsson (2008) and Vermeulen et al. (2012)). So does macroeconomic evidence. For example, Basu et al. (2013) find that consumption technology improvements lead to expansions in consumption, investment and hours, but investment technology improvements lead all three key variables to decline in the short run.[4] Basu, Fernald and Liu (2014) find that nominal rigidities in both the consumption sector and the investment sector are crucial for explaining the observed asymmetry of impulse responses to sector-specific technology shocks, as well as the evidence that the relative price of investment adjusts slowly to relative technology shocks.[5] For our results to hold, in addition to nominal rigidities, we require that shocks to investment and consumption technology not be perfectly symmetric. *Prima facie* evidence to this effect is provided by the fact that the

[3] See Barsky, House and Kimball (2007).

[4] The importance of investment technology shocks for aggregate fluctuations is stressed by Greenwood, Hercowitz and Krusell (2000), Fisher (2006) and Justiniano, Primiceri and Tambalotti (2010).

[5] See also Moura (2018).

relative price of investment goods not only has a trend, but also fluctuates over time relative to this trend (in simple models, the relative price of investment reflects relative technology, at least over long periods of time). In addition, using Basu et al.'s (2013) series for sectoral technologies we find that investment-specific technology shocks are distinctly more volatile than consumption-specific technology shocks and the correlation between them is positive but far from one.

The purpose of this paper is to investigate the optimal conduct of monetary policy in an economy characterized by shocks to both consumption and investment sectors when these shocks are not identical. To this end, we develop a micro-founded welfare criterion that allows normative analysis, and we discuss the nature of the trade-off that the central bank confronts. We characterize the properties of the optimal policy under commitment, and compare the welfare properties of alternative monetary policy rules.

Our framework is a two-sector, closed-economy model in which one sector produces non-durable consumption goods and the other produces investment goods. Prices in both markets are subject to the Calvo pricing friction. Labor and capital are immobile across sectors, and nominal wages are assumed to be flexible. Following the influential analysis of Rotemberg and Woodford (1997), we obtain a quadratic approximation to the social welfare function, and show that the deviation of welfare from its Pareto-optimal level depends not only on the variances of the consumption gap and PCE inflation, but also on the variances of the investment spending gap and investment price inflation. With two nominal frictions and only one instrument, the central bank is confronted with a nontrivial trade-off: indeed, it is generally impossible to stabilize inflation and the output gaps in both sectors simultaneously.[6]

We document that the optimal policy represents a compromise between the sectoral welfare losses. Most importantly, we find that the second-best policy places disproportionately high weight on the investment sector, notwithstanding its small relative size in the economy. Moreover, we find that monetary rules that ignore investment price inflation incur sizable welfare losses. In our calibrated model, a rule that targets only consumer price inflation leads to average welfare losses that are considerably larger than those obtained under an alternative simple rule that targets only investment price inflation.

Extending our study of simple rules, we study the behavior of a hybrid rule that responds only to the two sectoral inflation rates, and find that its performance is nearly optimal if the weights on the two inflation rates are chosen correctly. We find that such a rule places considerable weight on investment inflation, and thus its performance cannot be approximated by a Taylor rule that targets the GDP deflator. Finally, we document that our results are robust to empirically plausible calibrations of the degree of price stickiness in the investment sector.

The literature on optimal monetary policy is vast, but most of its conclusions are drawn using models that abstract from capital accumulation. Important works include Erceg and

[6] As an aside, we note that our model does not display what Blanchard and Galí (2007) term the "divine coincidence," even though we assume that both real and nominal wages are fully flexible. This result shows that the divine coincidence result obtains only due to the strong auxiliary assumption that all production functions in the economy are hit by the same technology shock. Since this assumption is clearly unrealistic and made only for modeling simplicity, "divine coincidence" is probably not important for the conduct of monetary policy.

Levin (2006), Huang and Liu (2005), Aoki (2001), Benigno (2004), Mankiw and Reis (2003), and Ikeda (2015). Erceg and Levin investigate the optimal monetary policy properties of a model that features non-durable and durable consumption goods. Consistent with our results, they find that the monetary authority should over-weight durable consumption goods prices in the price index that it targets.[7] Huang and Liu document the importance of targeting the producer price index (PPI) besides the CPI, in a model that features an input-output production structure. Aoki presents a model with a sticky-price sector and an otherwise identical flexible-price sector, and show that the optimal monetary policy is to target sticky-price inflation, rather than a broad inflation measure. This result is generalized by Benigno, who shows that in a two-country model an inflation targeting policy in which higher weight is given to the inflation in the region with higher degree of nominal rigidity is nearly optimal.[8] Mankiw and Reis take an analytical approach to characterizing the optimal price index that a central bank should target as a function of a number of sectoral characteristics; their main conclusion is that central banks should assign a high weight to the nominal wage rate.[9] In a recent related paper, Ikeda shows that a trend towards a falling relative price of investment may increase the optimal inflation target up to around 2%. His work focuses on deriving the optimal inflation target rate on PCE inflation, in the context of an estimated medium-scale two-sector model with a downward trend in investment prices.

The paper is structured as follows. Section 3.2 outlines the dynamic general equilibrium

[7] See also the recent contribution by Barsky et al. (2016).

[8] The results of Aoki and Benigno thus generally support the Federal Reserve's procedure of targeting "core" rather than "headline" inflation.

[9] This particular conclusion depends on their belief that the average allocative wage in the US is very sticky in nominal terms. For evidence to the contrary, see Basu and House (2016).

model. Section 2.3 describes the solution method and parameter calibration. Section 2.4 discusses the second-order approximation to the welfare function. Section 2.5 examines characteristics of the optimal policy, and evaluates the performance of alternative rules. Section 2.6 presents conclusions and suggests directions for future research.

2.2 The model

Our model consists of two sectors that produce non-durable consumption goods and investment goods. Labor-augmenting technology in both sectors has a trend, and both production functions are subject to stationary TFP fluctuations around that trend. Thus, we allow for the existence of a trend in the steady-state relative price of investment. The relative price of equipment investment has consistently declined over the past four decades. Both product markets exhibit monopolistic competition, and nominal prices do not change continuously. Each household has two types of workers that are permanently attached to their respective productive sectors. Households display separable preferences in the consumption good and in hours worked supplied to the two sectors. Labor markets are competitive. To finance consumption, households invest in riskless bonds and hold the sectoral capital stocks.

2.2.1 Firms

The model economy features two distinct sectors producing non-durable consumption goods (sector c) and investment goods (sector i). Each sector comprises a continuum of monopolistically competitive firms producing differentiated products. Let $Y_{j,t}$ denote sector-j output (real value added), for $j = \{c, i\}$:

$$Y_{j,t} = \left[\int_0^1 \left(Y_{j,t}(f) \right)^{\frac{1}{1+\theta_j}} df \right]^{1+\theta_j}$$

where $\theta_j > 0$ denotes the markup rate in the production composite of sector j. The aggregator chooses the bundle of goods that minimizes the cost of producing a given quantity of the sectoral output index $Y_{j,t}$, taking the price $P_{j,t}(f)$ of each good $Y_{j,t}(f)$ as given. The aggregator sells units of each sectoral output index at its unit cost $P_{j,t}$:

$$P_{j,t} = \left[\int_0^1 \left(P_{j,t}(f) \right)^{-\frac{1}{\theta_j}} df \right]^{-\theta_j}$$

It is natural to interpret $P_{j,t}$ as the price index for real value added in each sector. Thus, $P_{c,t}$ can be interpreted as the deflator for Personal Consumption Expenditures (PCE) or the Consumer Price Index (CPI).[10] $P_{i,t}$, on the other hand, denotes the price level in the investment sector. One can also define an aggregate price index P_t as:

$$P_t = \left(P_{c,t} \right)^{\phi} \left(P_{i,t} \right)^{1-\phi}$$

where ϕ is the steady-state output share of consumption. The aggregate price index, P_t, is, to a first-order approximation, the GDP deflator of this model economy.

[10] In our model of a closed economy, the two indexes are identical up to a first-order approximation, which is the order to which we will analyze the model.

Households' demand for each good is given by:

$$Y^d_{j,t}(f) = \left[\frac{P_{j,t}(f)}{P_{j,t}}\right]^{-\frac{1+\theta_j}{\theta_j}} Y_{j,t} \tag{2.1}$$

Each differentiated good is produced by a single firm that hires capital services $K_{j,t}(f)$ and a labor index $L_{j,t}(f)$ defined below. All firms within each sector face the same Cobb-Douglas production function, with an identical level of technology $Z_{j,t}$ and labor-augmenting technical progress $\Gamma_{j,t}$:

$$Y_{j,t}(f) = Z_{j,t}\left(K_{j,t}(f)\right)^{\alpha}\left(\Gamma_{j,t}L_{j,t}(f)\right)^{1-\alpha}$$

We thus separate total factor productivity (TFP) into two components: Z, the part that is subject to shocks, and Γ, which grows steadily at a constant rate. Capital and labor are perfectly mobile across the firms within each sector, but cannot be relocated between sectors. Each firm chooses $K_{j,t}(f)$ and $L_{j,t}(f)$, taking as given the sectoral wage index $W_{j,t}$, and the sectoral rental price of capital $P_{c,t}r^k_{j,t}$, where $r^k_{j,t}$ is the sectoral real rental rate of capital in units of consumption goods. The conditional factor demand functions derived from the cost-minimization problem for labor and capital are, respectively:

$$W_{j,t} = MC_{j,t}(f)(1-\alpha)\frac{Y_{j,t}(f)}{L_{j,t}(f)}$$

$$P_{c,t}r^k_{j,t} = MC_{j,t}(f)\,(\alpha)\,\frac{Y_{j,t}(f)}{K_{j,t}(f)}$$

Since capital and labor can flow freely across firms *within* the same sector, and production functions feature constant returns to scale, all firms within each sector have identical nominal marginal costs per unit of output, which are given by:

$$MC_{j,t} = \frac{\tilde{\alpha}}{Z_{j,t}\Gamma_{j,t}}(P_{c,t}r^k_{j,t})^{\alpha}(W_{j,t})^{1-\alpha} \tag{2.2}$$

where $\tilde{\alpha} \equiv \alpha^{-\alpha}(1-\alpha)^{\alpha-1}$.

We follow Calvo (1983) and assume that firms change their nominal prices only occasionally, and the probability that a firm changes its price is constant. Once a price is set, the firm must supply its differentiated product to meet market demand at the posted price. We follow Yun (1996) in assuming that the new price set in a generic period t is indexed to trend inflation.[11] Hence, even if the firm is not allowed to reoptimize its price, the preset price grows at the rate of trend inflation.

In Appendix B.1 we show that, under full indexation to trend inflation, the steady state coincides with the flexible-price steady state: each firm sets its price as a constant markup over marginal cost. This assumption guarantees that the steady state is not distorted by trend inflation. Also, in the steady state the monopolistic markup is completely offset by the subsidy τ_j. This assumption guarantees that the steady state of the model is not distorted by imperfect competition. Furthermore, full indexation to trend inflation guarantees that, in each sector, the log-linearized Phillips Curve is identical to the one obtained under zero

[11] Trend inflation in our model is induced by the presence of the trend component of TFP, Γ.

steady-state inflation.[12]

2.2.2 Households

We assume that there is a continuum of households indexed on the unit interval, and that each household supplies homogeneous labor services. Within every household, a fixed number of ν_c members work exclusively in the consumption sector, while the remaining ν_i members work exclusively in the investment sector. Each member of a given household $h \in [0,1]$ who works in sector $j = \{c, i\}$ has the same wage rate $W_{j,t}(h)$ and supplies the same number of hours $N_{j,t}(h)$. Households have no market power in the labor market, and the aggregation in each sectoral labor market is given by:

$$L_{j,t} = \nu_j \int_0^1 N_{j,t}(h) dh$$

In other words, a representative labor aggregator combines individual labor hours into a sectoral labor index $L_{j,t}$ using the same proportions that firms would choose. As a result of competitive labor markets, the sectoral wage index is the same across households within sector; that is, $W_{j,t}(h) = W_{j,t}$.

In each period, the household purchases $Y_{c,t}$ (or, equivalently, C_t) units of consumption goods at price $P_{c,t}$, and $Y_{i,t}$ (or I_t) units of investment goods at price $P_{i,t}$. Investment contributes to the formation of new capital stock in either consumption or investment sector; that is, $I_t = I_{c,t} + I_{i,t}$. Thus, the households face the following intertemporal budget

[12] For an analysis of the implications of trend inflation for New Keynesian models, see Ascari (2004).

constraint:

$$
\begin{aligned}
P_{c,t}C_t + P_{i,t}I_t + D_{t,t+1}B_{t+1} \leq\; & W_{c,t}(h)N_{c,t}(h) + W_{i,t}(h)N_{i,t}(h) + \\
& + P_{c,t}r^k_{c,t}K_{c,t} + P_{c,t}r^k_{i,t}K_{i,t} + \Pi_t + B_t - T_t
\end{aligned}
\tag{2.3}
$$

where B_{t+1} is a nominal state-contingent bond that represents a claim to one dollar in a particular event in period $t+1$, and this claim costs $D_{t,t+1}$ dollars in period t; $W_{j,t}(h)$ is sector-j nominal wage, $K_{j,t}$ is the beginning-of-period capital stock in sector j, Π_t is the profit share, and T_t is a lump-sum tax used by the government to finance subsidies to firms.

The capital stock in each sector evolves according to the following law of motion:

$$
K_{j,t+1} = (1-\delta)K_{j,t} + \Psi\left(\frac{I_{j,t}}{K_{j,t}}\right)K_{j,t} \tag{2.4}
$$

where the function $\Psi(\cdot)$ represents the adjustment cost in capital accumulation. We assume that $\Psi\left(\frac{I_j}{K_j}\right)$ satisfies $\Psi\left(\frac{I_j}{K_j}\right) = \frac{I_j}{K_j}$, $\Psi'\left(\frac{I_j}{K_j}\right) = 1$, and $\Psi''\left(\frac{I_j}{K_j}\right) = -\psi$ where $\psi > 0$, and $\frac{I_j}{K_j}$ is the share of investment to capital in sector j in steady state.

The household's expected lifetime utility is given by:

$$
\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \mathbb{W}_{t+s}(h) \tag{2.5}
$$

where the operator $\mathbb{E}_t$ here represents the conditional expectation over all states of nature, and the discount factor satisfies $0 < \beta < 1$. The period household utility function $\mathbb{W}_t(h)$ is additively separable with respect to the household's consumption C_t and the leisure of each household member:

$$\mathbb{W}_t = \mathbb{U}(C_t) - \mathbb{V}^c(N_{c,t}(h)) - \mathbb{V}^i(N_{i,t}(h)) \tag{2.6}$$

The subutility functions are defined as follows:

$$\mathbb{U}(C_t) = \frac{C_t^{1-\sigma}}{1-\sigma}$$

$$\mathbb{V}^c(N_{c,t}) = \upsilon_c \frac{N_{c,t}(h)^{1+\eta}}{1+\eta}$$

$$\mathbb{V}^c(N_{i,t}) = \upsilon_i \frac{N_{i,t}(h)^{1+\eta}}{1+\eta}$$

where the parameters σ, υ_c, υ_i and η are all strictly positive.

Each household h maximizes (2.5) with respect to each of its components, subject to the budget constraint in (2.3) and the capital laws of motion in each sector in (2.4). The first order conditions for the utility-maximizing problem are given by

$$P_{c,t}\lambda_t = C_t^{-\sigma} \tag{2.7}$$

$$\upsilon_j N_{j,t}(h)^{\eta} = \frac{w_{j,t}}{C_t^{\sigma}} \tag{2.8}$$

$$1 = \beta \mathbb{E}_t \left[\frac{R_t^n}{\Pi_{c,t+1}} \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \right] \tag{2.9}$$

$$q_{i,t} = q_{j,t}^k \left[\Psi' \left(\frac{I_{j,t}}{K_{j,t}} \right) \right] \tag{2.10}$$

$$q_{j,t}^{k}=\beta\mathbb{E}_{t}\left(\frac{C_{t+1}}{C_{t}}\right)^{-\sigma}\left\{q_{j,t+1}^{k}\left[1-\delta+\Psi\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)-\Psi'\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)\right]+r_{j,t+1}^{k}\right\} \tag{2.11}$$

where $w_{j,t}=\frac{W_{j,t}}{P_{c,t}}$ is the j-sector real wage, R_t^n is the time-t gross nominal interest rate, $\mathbb{E}_t\Pi_{c,t+1}$ represents the expected gross inflation rate in the consumption sector.

Denote by $q_{j,t}^k=\frac{\lambda_{j,t}^k}{\lambda_t P_{c,t}}$ the shadow value of j-sector capital stock in units of consumption goods. Then, Equations (2.10) and (2.11) become:

$$q_{i,t}=q_{j,t}^{k}\left[\Psi'\left(\frac{I_{j,t}}{K_{j,t}}\right)\right]$$

$$q_{j,t}^{k}=\beta\mathbb{E}_{t}\left(\frac{C_{t+1}}{C_{t}}\right)^{-\sigma}\left\{q_{j,t+1}^{k}\left[1-\delta+\Psi\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)-\Psi'\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)\right]+r_{j,t+1}^{k}\right\} \tag{2.12}$$

where the last equation makes use of Equation (2.7) to eliminate the Lagrange multiplier λ_t.

The left-hand side of (2.12) represents the cost of acquiring a marginal unit of sector-j capital today; the right-hand side captures the benefit of holding one extra unit of sector-j capital which consists of the expected discounted future resale value and the expected rental value. The discount factor is the intertemporal marginal utility of consumption.

2.2.3 Fiscal and Monetary Policy

The government's budget is balanced in every period: lump-sum taxes equal output subsidies period by period. For simplicity, we assume that there are no government purchases.

In our analysis, the short-term nominal interest rate is used as the instrument of monetary policy, and we assume that the policymaker is able to commit to a time-invariant rule. We consider alternative specifications of the monetary policy rule. As discussed by Sveen (2014), all the rules that we will consider ensure model determinacy for plausible calibrations of the parameter that governs investment price stickiness.

2.2.4 Market Clearing

In equilibrium, the markets for bonds, consumption, investment, capital rentals and labor all clear. Bond market clearing implies that $B_t = 0$ for all t. Labor market clearing implies that $\int_0^1 L_{c,t}(f)df + \int_0^1 L_{i,t}(f)df = L_t$. Capital market clearing implies $\int_0^1 K_{c,t}(f)df + \int_0^1 K_{i,t}(f)df = K_t$. Goods market clearing in the two sectors implies that $Y_{c,t} = C_t$ and $Y_{i,t} = I_t$, where $I_t = I_{c,t} + I_{i,t}$. Consistent with the current procedure of the National Income and Product Accounts (NIPA), real GDP is defined as $Y_t = (C_t)^{\phi} (I_t)^{1-\phi}$, where ϕ is the expenditure share of consumption.

2.3 Solution and calibration

Given fiscal and monetary policy, an equilibrium in this economy consists of prices and allocations such that (i) taking prices and real wages as given, each household's allocation solves its utility maximization problem; (ii) taking wages and all other firms' prices as given, each firm's factor demands and output price solve its profit maximization problem; (iii) the markets for bonds, labor, capital, and sectoral outputs all clear.

The trends in sectoral technologies render the model nonstationary. We focus on a stationary equilibrium with balanced growth in which output, consumption, investment, the capital stock, and the real wage all grow at constant rates, while hours worked remain constant. Furthermore, if trend growth in technology in the investment sector is faster than its consumption-sector counterpart, investment and capital will grow at a faster rate than consumption or GDP, and the relative price of investment will have a downward trend.[13] We study the dynamic properties of the model by taking a log-linear approximation of the equilibrium conditions around the balanced growth path.[14]

To close the model, we have to specify sectoral inflation dynamics. Sectoral Phillips curves are expressed by:

$$\pi_{c,t} = \tilde{\beta}\mathbb{E}_t \pi_{c,t+1} + \kappa_c v_{c,t} \tag{2.13}$$

$$\pi_{i,t} = \tilde{\beta}\mathbb{E}_t \pi_{i,t+1} + \kappa_i v_{i,t} \tag{2.14}$$

where the growth-adjusted discount factor $\tilde{\beta} = \beta(\gamma_c^{1-\alpha}\gamma_i^{\alpha})^{1-\sigma}$, $\kappa_j = \frac{(1-\xi_j)(1-\xi_j\tilde{\beta})}{\xi_j}$, and $v_{j,t}$ denotes sector-j real marginal costs. C-sector real marginal costs are expressed in consumption units, whereas i-sector real marginal costs are expressed in investment units. The relative price of investment is defined in changes by:

$$q_{i,t} = q_{i,t-1} + \pi_{i,t} - \pi_{c,t} \tag{2.15}$$

[13] Stationarity is therefore obtained by appropriate variable transformations, as shown in Appendix B.2.
[14] The resulting model log-linearized behavioral equations are listed in Table B.2.1 in Appendix B.2.

As shown in Appendix B.3, under Woodford's (2003) definition of the natural rate, sectoral real marginal costs can be rewritten as a function of consumption, investment, and relative price gaps:[15]

$$v_{c,t} = \left[\frac{(1+\eta)}{1-\alpha} - (1-\sigma)\right]\tilde{c}_t$$

$$v_{i,t} = \left(\frac{\alpha+\eta}{1-\alpha}\right)\tilde{i}_t + \sigma\tilde{c}_t - \tilde{q}_{i,t}$$

where $\tilde{x}_t$ denotes the devation of variable x_t from its flexible-price counterpart, that is $x_t - x_t^*$. Then, the sectoral Phillips curves in (2.13) and (2.14) can be expressed as:

$$\pi_{c,t} = \tilde{\beta}\mathbb{E}_t\pi_{c,t+1} + \kappa_c\left[\left(\frac{\alpha+\eta}{1-\alpha} + \sigma\right)\tilde{c}_t\right] \tag{2.16}$$

$$\pi_{i,t} = \tilde{\beta}\mathbb{E}_t\pi_{i,t+1} + \kappa_i\left[\left(\frac{\alpha+\eta}{1-\alpha}\right)\tilde{i}_t + \sigma\tilde{c}_t - \tilde{q}_{i,t}\right] \tag{2.17}$$

Thus, as in the standard one-sector New Keynesian model, sectoral inflation dynamics respond to their respective measures of slack. In fact, the consumption-sector Phillips curve is equivalent to the one resulting from the one-sector New Keynesian model. However, in addition to the investment gap, investment inflation dynamics depend upon the consumption gap as well as the deviation of the relative price of investment from its flexible-price counterpart. Intuitively, inefficiently high consumption induces a wealth effect that reduces hours worked in the investment sector; this leads to inefficiently high investment-sector wages and creates inflationary pressures. Also, when the relative price of investment is higher than

[15] There exist two distinct definitions of the natural rate of output in New Keynesian models with endogenous capital accumulation. The difference between the two is discussed in Section 2.4.

its flexible-price level due to suboptimally high markups, investment-good producers adjust their prices downward to avoid incurring output losses.

The stationary components of sectoral technology follow a bivariate AR(1) process in logs:

$$\begin{pmatrix} z_{c,t} \\ z_{i,t} \end{pmatrix} = \begin{pmatrix} \rho_{z_c} & 0 \\ 0 & \rho_{z_c} \end{pmatrix} \begin{pmatrix} z_{c,t-1} \\ z_{i,t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon^z_{c,t} \\ \varepsilon^z_{i,t} \end{pmatrix}$$

where the innovations are assumed to be i.i.d. and are allowed to have a non-zero contemporaneous correlation. The trend growth rates γ_c and γ_i are assumed to be constant.

The model is calibrated at a quarterly frequency. We assume that the utility from consumption takes the logarithmic form ($\sigma = 1$). We set $\eta = 1/4$, corresponding to a Frisch elasticity of labor supply of 4. We set $\alpha = 1/3$, so that the labor share in each sector is 2/3. We set $\gamma_c = 1.004$ and $\gamma_i = 1.01$. The implied real per-capita consumption growth rate is $\gamma_c^{1-\alpha}\gamma_i^{\alpha} = 1.006$ or about 2.4% percent per year, which is close to the data. We calibrate δ so that the steady-state investment-to-capital ratio is about 0.15 per annum. In particular, the steady-state capital law of motion implies that

$$\tilde{\delta} \equiv \frac{\hat{I}}{\hat{K}} = 1 - \frac{1-\delta}{\gamma_i}$$

This relation implies that $\delta = 0.0279$ per quarter. We assume that $\beta = 0.995$, consistent with a steady-state real interest rate $r = \beta\left(\gamma_c^{1-\alpha}\gamma_i^{\alpha}\right)^{\sigma} = 1.0111$, or about 4.5% per year. We set the steady-state inflation rate for PCE, $\Pi_c = 1.005$, or 2% per annual, which implies that

$\Pi_i = 1.0011$, or about 0.4% per annual. We set the markup rates such that $\mu_c = \mu_i = 1.11$, which are in line with micro studies (Basu and Fernald (1997)). As a benchmark, we set $\xi_c = \xi_i = 0.75$, implying that price contracts last on average for 4 quarters in each sector. The share of the investment sector in both output and employment $1-\phi$ is set equal to 0.22, implying that the output share of consumption $\phi = 0.78$.[16] These reflect their empirical counterparts in the National Income and Product Accounts. Finally, we set $\psi = 2$, to reproduce the degree of investment volatility relative to output observed in the data.

To calibrate the variance of shocks, we use the use the consumption- and investment-sector series on total factor productivity estimated by Basu et al. (2013). The estimated persistence parameters for sectoral TFPs are $\rho_{z_c} = 0.98$ and $\rho_{z_i} = 0.95$. The estimated standard deviations of consumption and investment TFP innovations are $\sigma_{z_c} = 0.53\%$ and $\sigma_{z_i} = 1.33\%$. Importantly, our estimates indicate that $\sigma_{z_i,z_c} = 4.1342(10)^{-5}$, implying that sectoral TFP innovations are positively correlated, with a correlation coefficient of about 0.58.[17] In the benchmark economy, the monetary authority is assumed to follow a Taylor rule of the form $r_t^n = 1.5\pi_{c,t} + 0.5\tilde{y}_t$.

Table 2.1 presents selected business cycle statistics for the benchmark economy: the unconditional standard deviation of output is in line with its empirical counterpart; also,

[16] These determine the employment size parameters υ_c and υ_i in the subutility functions for leisure.

[17] Basu et al.'s (2013) TFPs are expressed in terms of log differences. We take the cumulative sum to obtain log levels of sectoral TFPs. To estimate the parameters of the bivariate technology shock process we use a seemingly unrelated regression (SUR) model. Also, we allow for time-varying linear trends, as a Bai-Perron test indicates that sectoral technologies contain at least one significant trend break in each sector. Finally, since Basu et al. (2013) provide us with annual data, we take the fourth root of annual persistence parameters and divide annual standard deviation parameters by four to obtain quarterly figures.

	Std. deviations				1st order autocorr.				Contemp. correlations			
	y	c/y	i/y	q_i/y	y	c	i	q_i	c, y	i, y	q_i, y	c, i
Model	1.00%	0.63	2.67	0.50	0.70	0.73	0.73	0.87	0.91	0.94	-0.09	0.71
Data	0.82%	0.45	2.97	0.85	0.89	0.82	0.89	0.75	0.82	0.95	-0.20	0.62

Table 2.1: Business cycle statistics

Note: All variables are in logarithms and have been detrended with the HP filter. The moments in this table are population moments computed from the solution of the model. We generate 500 simulations, each with the same number of observations available in the data (224), and report the average HP-filtered moments across these simulations. The monetary authority is assumed to follow a Taylor rule of the form $r_t^n = 1.5\pi_{c,t} + 0.5\tilde{y}_t$ where π_c is PCE inflation and $\tilde{y}$ is the aggregate output gap.

consistent with the data, consumption is about half as volatile as aggregate output whereas investment is about three times as volatile as output.[18] The standard deviation of the relative price of investment implied by the model is somewhat smaller than the one observed in the data. The persistence generated by the model is high, but weaker than in the data for real output, consumption and investment, and stronger for the relative price of investment. In terms of comovements, the model performs remarkably well in capturing the contemporaneous correlations among the key variables. In line with the data, it captures the fact that both consumption and investment are highly correlated with output, the modest countercyclicality of the relative price of investment, and the positive comovement between the two sectoral outputs.

[18] In our model, "consumption" is naturally interpreted as comprising non-durable goods and services, whereas "investment" includes equipment, structures and residential investment.

2.4 The welfare function

We formally derive a second-order approximation to the social welfare function, and we compute its deviation from the welfare of the Pareto-optimal equilibrium, following Rotemberg and Woodford (1997). In our model, a Pareto-optimal equilibrium obtains when both consumption and investment sectors have fully flexible nominal prices. One should note that, however, in the context of sticky-price models with capital accumulation, there exist two distinct definitions of the natural rate of output.[19] One can define the natural rate of output based on the capital stocks implied by the flexible-price model (that is, $k^*_{j,t}$, for $j = \{c, i\}$), or the capital stocks that actually exists in the economy in that period (that is, the capital stock from the sticky-price model, $k_{j,t}$, for $j = \{c, i\}$).[20] In this paper, we adopt the latter definition of natural rate, proposed by Woodford (2003): thus, if the model economy operates under sticky-prices, then it is the period-t capital stock from that model that determines the current natural rate of output. We opt for this definition of natural rate of output, based on the *actual* capital stock, because it closely corresponds to what is generally thought of as *potential* output.

[19] This difference arises only in models with endogenous capital accumulation. In such models, the natural rate of output in period-t depends upon the period-t capital stock, in addition to the model's exogenous disturbances

[20] The first concept has been advocated by Neiss and Nelson (2003), who construct their definition of the natural rate of output by assuming that the relevant capital stock is the one that which would have been in place had the economy always existed in a flexible-price world. To be precise, while the initial capital stock $k_{j,0}$, for $j = \{c, i\}$, is given, the capital stock that defines the natural rate of output in all subsequent periods is that from the flexible-price model, which is denoted by $\{k^*_{t+1}\}^{\infty}_{t=0}$.

As derived in Appendix B.5, the unconditional welfare losses can be expressed as follows:

$$\mathbb{L} \simeq \frac{1}{2}\left[\frac{(1+\eta)}{1-\alpha} - (1-\sigma)\right] var\left(c - c^{*}\right) +$$

$$+\frac{1}{2}\left[\frac{1-\phi}{\phi}\left(\frac{1+\eta}{1-\alpha}\right)\right] var(i - i^{*}) + \frac{1}{2}\left(\frac{\theta_c}{1+\theta_c}\right)\left(\frac{1-\tilde{\beta}\xi_c}{1-\xi_c}\right)\frac{1}{\kappa_c} var(\pi_c) +$$

$$+\frac{1}{2}\frac{1-\phi}{\phi}\left(\frac{\theta_i}{1+\theta_i}\right)\left(\frac{1-\tilde{\beta}\xi_i}{1-\xi_i}\right)\frac{1}{\kappa_i} var(\pi_i) - \left[\frac{1-\phi}{\phi}\left(1+\eta\right)\right] cov(l_i^{*}, i - i^{*}) \tag{2.18}$$

In our two-sector economy the variance of the consumption gap, $var\left(c - c^{*}\right)$, and the variance of the PCE inflation rate, $var(\pi_c)$, reduce household utility, as they do in models that abstract from endogenous capital accumulation. In addition, the variance of the investment gap, $var(i - i^{*})$, also reduces household utility. In fact, as stressed by Edge (2003), the *composition* of output has welfare implications in models that account for endogenous capital accumulation. In our two-sector economy, this feature extends to inflation: since investment-goods prices are sticky in nominal terms, welfare also depends upon the variation in investment inflation, $var(\pi_i)$.[21]

Under the baseline calibration, the two sectors have the same markups and the same degree of price stickiness.[22] Thus, the welfare-function weight of PCE inflation relative to invest-

[21] As shown by Woodford (2003) and Erceg, Henderson and Levin (2000), inflation variation lowers welfare, since inflation in a given sector leads to price dispersion, which generates an inefficient allocation of production across firms.

[22] In each sector, the extent to which inflation variation affects household's utility is increasing in the degree of price stickiness and in the elasticity of substitution among goods. For given inflation volatility, higher price stickiness is associated with higher price dispersion and higher welfare costs. Also, when firms operate in highly competitive markets, price dispersion becomes particularly welfare diminishing, because even a relatively small dispersion of prices corresponds to considerable output dispersion.

ment inflation is determined by the output share of consumption relative to investment (that is, about 4 to 1). Finally, a positive covariance between the investment gap and the natural rate of hours worked in the investment sector raises utility. It is difficult to place an intuitive interpretation on this term which, however, makes only a minor contribution to the welfare results reported below.[23]

2.5 Results

In our two-sector model monetary policy is confronted with a non-trivial trade-off if there are nominal rigidities in the pricing of both consumption and investment goods, and if the shocks to the two sectors are asymmetric. In this section we begin by formalizing this result for a simpler version of our model. To generalize, we then illustrate the stabilization problem faced by the central bank in response to a consumption-technology shock when both consumption and investment prices are sticky. Our impulse response analysis serves two purposes. First, it highlights that in response to asymmetric sectoral shocks the attempt to stabilize fluctuations in one sector inevitably generates larger fluctuations in the other one. Hence, the second-best equilibrium – the optimal monetary policy that minimizes unconditional welfare losses under full commitment – represents a compromise between sectoral fluctuations. Second, our impulse response analysis provides intuition for why optimal policy places relatively more weight on investment-sector stabilization. Later in this section, in fact, we examine the welfare properties of alternative monetary rules and

[23] In addition, this term is nil whenever the investment gap is closed.

show that, in general, welfare losses that arise from the investment sector are one order of magnitude larger than those stemming from the consumption sector. We finally show that the degree of rigidity of investment prices crucially affects the implications for optimal monetary policy.

2.5.1 The monetary policy trade-off

In general, when both consumption and investment prices are sticky the monetary authority cannot attain the flexible-price equilibrium. Given the complexity of our model, we are able to show this result analytically only for the special case in which there are no adjustment costs, and labor supply is infinitely elastic.

Proposition 1 *Assume that there are no sectoral adjustment costs ($\psi = 0$) and thus a unique capital stock for the economy with law of motion $k_{t+1} = (1-\tilde{\delta})k_t + \tilde{\delta}i_t$. Also, assume that labor supply is perfectly elastic ($\eta = 0$). If prices in both sectors adjust at a finite speed ($\xi_c > 0$ and $\xi_i > 0$), then there exists no monetary policy that can attain the Pareto optimal allocation unless the two sectors are subject to identical disturbances ($z_{c,t} = z_{i,t}$ for all t).*

Proof. First, note that the relative price *gap* evolves according to:

$$\Delta\tilde{q}_{i,t} = \pi_{i,t} - \pi_{c,t} - \Delta q^*_{i,t} \tag{2.19}$$

which follows easily from equation (2.15). The assumptions of no adjustment costs and infinite Frisch elasticity guarantee that rental rates of capital and wages are equalized across sectors in each period, in units of consumption goods. As a result, in the flexible-price equilibrium relative price dynamics are solely governed by productivity differences (that is $q^*_{i,t} = z_{c,t} - z_{i,t}$). Thus, the flexible-price dynamics of the relative price gap evolves as:

$$\Delta q^*_{i,t} = \Delta z_{c,t} - \Delta z_{i,t} \tag{2.20}$$

Now suppose there was a monetary policy rule that would make the equilibrium allocation under sticky prices Pareto optimal. Then, in such an equilibrium, the gaps would be zero in every period, including the marginal cost gaps and the relative price gap (that is, $\tilde{q}_{i,t} = 0$ for all t). It follows from (2.13) and (2.14) that $\pi_{c,t} = \pi_{i,t} = 0$ for all t. In turn, this implies that $\Delta q_{i,t} = 0$ for all t, and (2.19) and (2.20) imply that $\pi_{i,t} - \pi_{c,t} = \Delta z_{c,t} - \Delta z_{i,t}$. This last equality contradicts the conclusion that $\pi_{i,t} = \pi_{c,t} = 0$ unless $\Delta z_{c,t} = \Delta z_{i,t}$ for all t. ■

To provide an intuition regarding the nature of the monetary policy trade-off, we begin by combining the log-linearized versions of the first-order conditions for bonds, (2.9), investment, (2.10), and capital, (2.11), together with the definition of the relative price of investment, (2.15). Using these equations, one can show that the Euler equation for sector-j Tobin's Q can be written as:

$$q^k_{j,t} - q_{i,t} = \tilde{\beta}\mathbb{E}_t\left(q^k_{j,t+1} - q_{i,t+1}\right) + \left(1 - \tilde{\beta}(1-\tilde{\delta})\right)\mathbb{E}_t(r^k_{j,t+1} - q_{i,t+1}) - (r^n_t - \mathbb{E}_t\pi_{i,t+1}) \tag{2.21}$$

where $r^n_t - \mathbb{E}_t\pi_{i,t+1}$ denotes the investment-real interest rate. By solving Equation (2.21) forward one obtains:

$$q^k_{j,t} - q_{i,t} = \sum_{s=0}^{\infty}\tilde{\beta}^s\mathbb{E}_t\left\{\left(1 - \tilde{\beta}(1-\tilde{\delta})\right)\left(r^k_{j,t+s+1} - q_{i,t+s+1}\right) - (r^n_{t+s} - \pi_{i,t+s+1})\right\} \tag{2.22}$$

The last equation shows that the current Tobin's Q of sector j (measured in units of investment goods) depends upon the discounted sum of the rental value of sector-j capital (in units of investment goods) as well as the discounted sum of the investment-real interest rate.[24] Moreover, for standard calibrations the term $1 - \tilde{\beta}(1 - \tilde{\delta})$ takes values around 0.05. Thus, Tobin's Q is especially sensitive to the path of the investment-real interest rate: the investment-real interest rate channel dominates the response to capital returns. In turn, by the log-linearized FOC for investment, (2.10), the Tobin's Q (in investment good units) is a sufficient statistic for investment demand. As usual, agents' demand for investment depends upon the shadow value of capital, $q^k_{j,t}$, relative to its purchase price, $q_{i,t}$.[25]

Having understood the key forces driving investment demand, we move to analyzing the dynamic behavior of the model economy in response to disturbances that are not symmetric across sectors. Figure 2.2 reports the impulse response functions to a one-standard-deviation consumption-specific technology improvement. As shown by Basu et al. (2013), under flexible prices and logarithmic utility, consumption-specific technology shocks are neutral in the sense that they have no effect other than increasing the quantity of consumption (and the relative price of investment) by the amount of the technology improvement. Thus, note that under flexible prices, both investment and hours worked remain at their steady-state values. This is the sense in which, under neoclassical conditions, consumption technology shocks cannot drive economic fluctuations, since they do not produce the comovements

[24] Note that the investment-real interest rate can also be expressed as the consumption real interest rate net of expected capital gains/losses, that is $(r^n_t - \mathbb{E}_t \pi_{c,t+1}) - \mathbb{E}_t \Delta q_{i,t+1}$.

[25] Here, both the shadow value of capital and the price of investment goods are expressed in consumption good units.

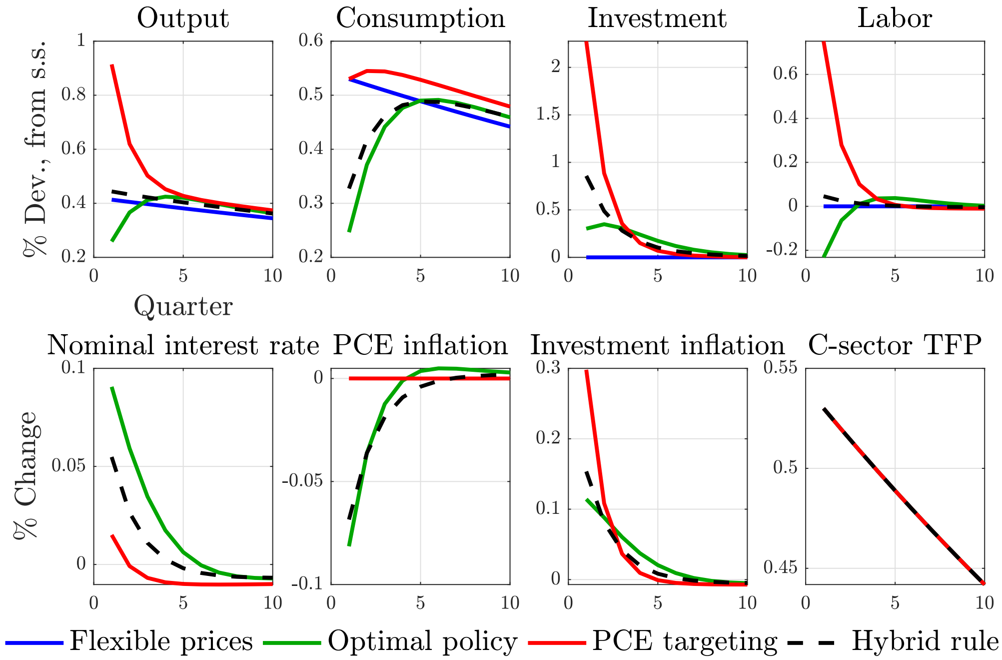


Figure 2.2: Impulse responses following a consumption-sector technology shock
Note: The correlation between technology shocks is set to zero when computing the impulse responses.

characteristic of business cycles. However, with sticky prices combined with the suboptimal but realistic policy of a Taylor rule that targets consumer prices, note that consumption technology shocks *do* produce positive comovements; the fluctuations in consumption, investment and labor input are qualitatively characteristic of business cycles, as is the ranking of volatility among investment, output and consumption.

The intuition behind the impulse responses is as follows. An improvement in consumption technology naturally increases the output of consumption goods. This raises the marginal product of capital in the consumption sector, which wishes to invest in capital goods. Under sticky investment-goods prices, agents know that investment goods are temporarily cheap (the increase in demand will drive up their prices over time, but due to the Calvo friction, the nominal price of investment goods is basically unchanged on impact). Thus, there is a large spike in the demand for investment, which leads to a surge in investment inflation and a large increase in labor input.

When both consumption and investment prices are subject to nominal rigidities, an optimizing central bank faces a trade-off among competing ends. In response to a consumption-specific technology improvement, most firms in the consumption sector are unable to adjust prices downward to keep their markups constant. The result is that markups in the consumption sector rise and therefore consumption becomes inefficiently low, leading to a *negative* consumption gap and expected consumer price deflation. As the downward adjustment of consumption prices is imperfect, the relative price of investment is inefficiently low. This induces agents to demand too many investment goods, thereby generating a *positive* investment gap, and investment inflation. The monetary authority is unable to close both output gaps (or alternatively, to stabilize both inflation rates) because it can influence the economy only through a single instrument, the nominal interest rate. To stimulate consumption, the central bank must cut the nominal interest rate to offset the deflationary pressures in the consumption sector. However, this action would generate an even larger investment gap, by further reducing the investment real interest rate (see Equation (2.22)). On the other hand, to close the investment gap, the central bank should raise the nominal interest rate, but this policy would reduce consumption even further.

As potential output cannot be attained in both sectors, the optimal policy is a compromise between these two goals. In Figure 2.2, one can notice that the optimal policy succeeds in minimizing the investment gap by raising the nominal rate significantly. The cost of achieving a relatively small investment gap is to keep consumption below potential for five quarters, and aggregate output below potential for about two quarters.[26]

Through the same lens, we now analyze the dynamic response of the model economy when the central bank targets only PCE inflation, but chooses the size of the coefficient on the consumer price inflation rate optimally.[27] By solely responding to the consumption sector, the central bank cuts the nominal rate to respond to the *c*-sector deflationary outcome. Although this results in nearly optimal consumption dynamics, significantly negative investment real rates further spur the demand for investment goods, resulting in large investment gap and investment inflation volatility.

Finally, a hybrid rule which optimally targets both consumption and investment inflation manages to closely replicate the consumption and investment responses obtained under optimal policy. This suggests that targeting investment inflation generally has desirable stabilization properties. In the following section, we analyze this issue in greater depth.

2.5.2 Welfare implications of alternative rules

From both a normative and positive perspective, simple feedback interest rate rules are often considered effective ways to conduct and communicate monetary policy. The Taylor (1993) rule, under which the central bank sets the short-term nominal interest rate in

[26] In fact, under optimal policy the consumption real interest rate is positive.
[27] Optimal coefficients of simple Taylor rules are chosen through a grid-searching algorithm.

response to fluctuations in inflation (and the output gap), is generally viewed as a simple but realistic description of monetary policy.[28] Our model suggests that the standard Taylor rule implemented with CPI/PCE inflation ignores some important variables in the welfare function, especially the investment inflation rate. Thus, we now investigate the welfare effects of various simple rules, and compare their performance to the optimal policy.

Table 2.2 displays the welfare losses under a set of interest rate rules. These allow the short-term rate to respond optimally to different combinations of PCE inflation, investment inflation, and sectoral output gaps. The results in Table 2.2 conform to expectations: a rule that strictly targets PCE inflation results in considerably large welfare losses. Specifically, under PCE-inflation targeting, the economy incurs welfare losses that are about three times larger than those of the optimal policy. Somewhat surprisingly, a rule that instead strictly targets investment inflation performs considerably better than the PCE targeting rule, notwithstanding the much smaller size of the investment sector. In other words, targeting investment inflation as opposed to PCE inflation has more desirable stabilizing properties.[29] Importantly, a Taylor rule that optimally assigns about equal weight to PCE and investment inflation performs nearly as well as the optimal rule. As data on both PCE and investment inflation can be observed and communicated readily, we believe that this rule is a good candidate for realistic policy analysis.

[28] Note that in his original paper, Taylor used inflation in the GDP deflator to implement his rule! While still far from optimal policy, we will show that targeting the GDP deflator performs significantly better in welfare terms than targeting PCE inflation.

[29] Note that adding the consumption (investment) gap to the PCE (investment) inflation rule as an additional targeting variable does not visibly affect welfare results. This is because the divine coincidence result holds for each sector in our model, although it does not hold in the aggregate.

Monetary rule target(s)	Welfare losses		Rel. weights in opt. price index				
	Total	Rel. to OP	π_c	π_i	$\tilde{c}$	$\tilde{i}$	π_y
Optimal Policy	1.39	1					
Monetary rules that target sectoral variables							
PCE (π_c)	4.23	3.05	1.00				
π_c, $\tilde{c}$	4.22	3.04	0.40		0.60		
π_i	3.05	2.19		1.00			
π_i, $\tilde{i}$	3.05	2.19		0.40		0.60	
π_c, π_i	1.65	1.19	0.55	0.45			
Monetary rules that target aggregate variables							
GDP deflator (π_y)	2.08	1.50					1.00

Table 2.2: Welfare costs of alternative policy rules

Note: Total welfare losses are expressed as a percent of steady-state consumption (multiplied by 100). The third column reports welfare losses relative to those incurred under optimal policy.

At this point one may wonder whether a rule that targets an "aggregate" price index, akin to the GDP deflator, might be a good approximation of the optimal rule. The bottom line of Table 2.2 shows that such rule leads to welfare losses of 2.08% of steady-state consumption, which is about 1.50 times the loss under optimal policy. Therefore, our results suggest that it is crucial to target investment-specific variables more than proportionally.

To provide further insight on the importance of targeting investment inflation relative to PCE inflation, Figure 2.3 displays the welfare losses incurred under alternative calibrations of the Taylor rule coefficients attached to the two inflation indexes. Figure 2.3 (left panel) delivers a clear message: ignoring the investment inflation index typically creates significant welfare losses. On the other hand, when a standard Taylor rule accounts also for investment inflation, the welfare losses are quite close to those obtained under the optimal rule. Figure 2.3 (center and right panel) decompose the welfare losses into their sectoral components. A central bank that is solely concerned with PCE stabilization generates sizable welfare losses in the investment sector. When the monetary authority also targets investment inflation, the consumption sector becomes relatively more volatile. Overall, our model suggests that the second option is preferred from a welfare perspective: investment components of welfare are much larger than those arising from the consumption sector. As a result, their contribution is essential to account for the findings in Table 2.2.

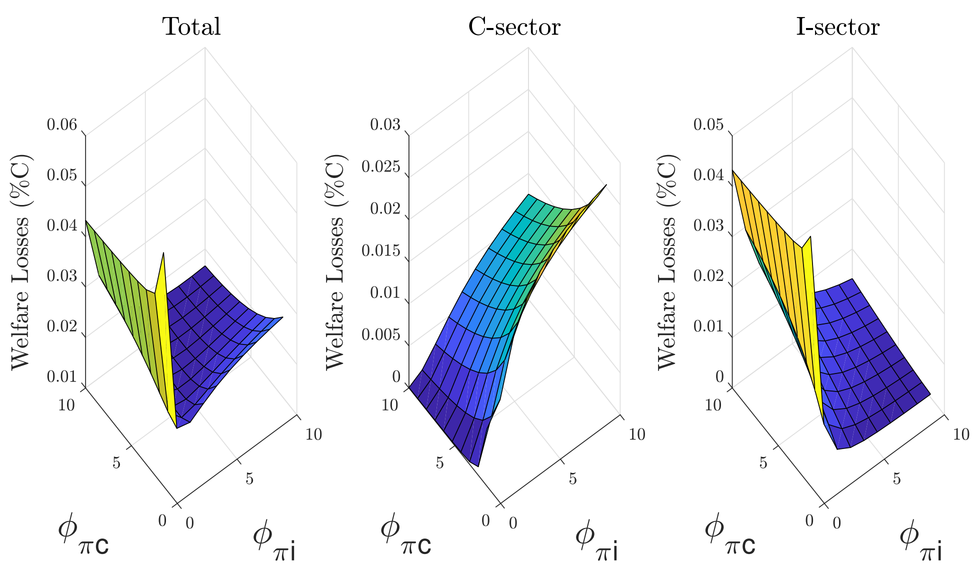


Figure 2.3: Welfare costs under alternative calibrations of the coefficient in the PCE-investment inflation hybrid rule

Note: The rule that we consider in these simulations is $r_t^n = \phi_{\pi_c}\pi_{c,t} + \phi_{\pi_i}\pi_{i,t}$. Welfare losses are expressed as percent of steady-state consumption.

These results stem from the fact that the shadow value of capital is approximately unchanged in the wake of temporary disturbances. The illustration of this point follows the insights in Barsky, House and Kimball (2007), who first highlighted the dynamic implications of the near-constancy of the shadow value of long-lived goods. In our model, the shadow value of capital is defined by Equation (2.12). Abstracting from adjustment costs, Equation (2.12) reads:[30]

$$q^k_{j,t} = \beta \left[\mathbb{E}_t \sum_{i=1}^{\infty} \left(\frac{C_{t+i}}{C_{t+i-1}} \right)^{-\sigma} [\beta(1-\delta)]^i \, MPK_{j,t+i+1} \right] \tag{2.23}$$

for $\{j = c, i\}$. As pointed out by Barsky, House and Kimball (2007), the shadow value of capital, $q^k_{j,t}$, will be largely unaffected by transitory shocks as long as the depreciation rate of the capital stock, δ, is sufficiently low. In fact, this would imply a high stock-flow ratio: even relatively high transitory changes in the production of investment goods would have little effect on the capital stock, and hence on its shadow value. Also, importantly, a low depreciation rate implies that the shadow value of capital in (2.23) is largely influenced by marginal products of capital in the distant future. And these are close to their steady-state values if shocks are temporary.

The near-constancy of the shadow value of long-lived capital goods implies that the demand for investment goods displays an almost infinite elasticity of intertemporal substitution (IES): even a small rise in the price of the investment good today relative to tomorrow would cause people to delay their investment.[31] In contrast, (non-durable) consumption goods are subject to the consumption smoothing logic of the permanent income hypothesis.

[30] Note that Equation (2.12) is also solved forward and we denote $MPK_{j,t} = r^k_{j,t}$. Equation (B.7) in Appendix B.2 represents the version of Equation (2.12) that accounts for trend growth in technology.

[31] As discussed above, in their investment decision agents compare the marginal (or shadow) value of capital ($q^k_{j,t}$) to its marginal cost ($q_{i,t}$). Since the former is roughly constant, changes in the latter generate sizable fluctuations in investment demand.

As a result, consumption is much less responsive to temporary price changes. This intrinsic difference has profound implications for monetary policy: a small intertemporal distortion in the price of investment goods generates high investment (and output) fluctuations, resulting in sizable welfare losses. For this reason, it becomes important to stabilize the investment sector. On the other hand, PCE targeting in a two-sector model of consumption and investment is generally incidental.[32]

2.5.3 The role of investment price rigidity

In this section we ask how sectoral differences in price stickiness affect our results. In particular, we analyze how the implications for monetary policy change as we change the degree of investment price rigidity. Figure 2.4 illustrates the outcome of this inquiry. A PCE inflation targeting rule displays very poor welfare properties as long as the average duration of investment price contracts is higher than two and a half quarters. With shorter durations (low values of ξ_i) investment price dispersion is lower, and ignoring investment inflation comes at a lower cost. As ξ_i rises, a PCE targeting rule becomes highly suboptimal because the investment components of welfare losses dominate those originating from the consumption sector. This feature of multi-sector models with heterogeneous price stickiness was first analyzed in Aoki (2001) (Benigno (2004)) who show that, in a two-sector (two-region) framework with heterogeneous degree of nominal rigidities, it is nearly optimal to implement an inflation targeting policy in which higher weight is given to the inflation of

[32] While capital adjustment costs reduce the IES in investment, our quantitative results indicate that the IES in investment is nevertheless much higher than in consumption when capital adjustment costs are calibrated to reproduce the empirically-observed volatility of investment relative to output.

the stickier sector (region). These studies focus on the implications for monetary policy in models that features two sectors (regions) that are isomorphic to each other. That is, they are two otherwise identical final-good sectors producing non-durables that differ just with respect to their degree of nominal rigidity. Instead, in our framework the two sectors produce goods with intrinsically different characteristics.[33] Note that the hybrid rule performance is nearly optimal along the whole range of ξ_i. This is not surprising, since its coefficients are optimally set and it assigns different weights to the two inflation components as the nominal rigidity in the investment sector differs. Specifically, the coefficient on investment inflation rises as investment prices become more sticky.

In general, there is little microeconomic evidence on the frequency of price change of investment goods. However, available evidence supports high price stickiness in several categories of investment goods, both in the US and the Euro Area. According to Nakamura and Steinsson (2008), the median implied duration of prices of finished producer goods for the U.S. is 8.7 months and some categories exhibit an even higher duration: 26.5 months for machinery and equipment and 19.1 months for furniture and household durables. Similarly, Alvarez et al. (2006) and Vermeulen et al. (2012) summarize the vast evidence on micro price-setting recently obtained for Euro Area countries, and find that investment goods are the stickier components of producer prices: they report price stickiness of "capital goods" of 0.91 at monthly frequency, which would correspond to a quarterly frequency of as high as 0.75, or four quarters. In light of these studies, we find that price stickiness in

[33] In this respect, our results are closer to Erceg and Levin (2006).

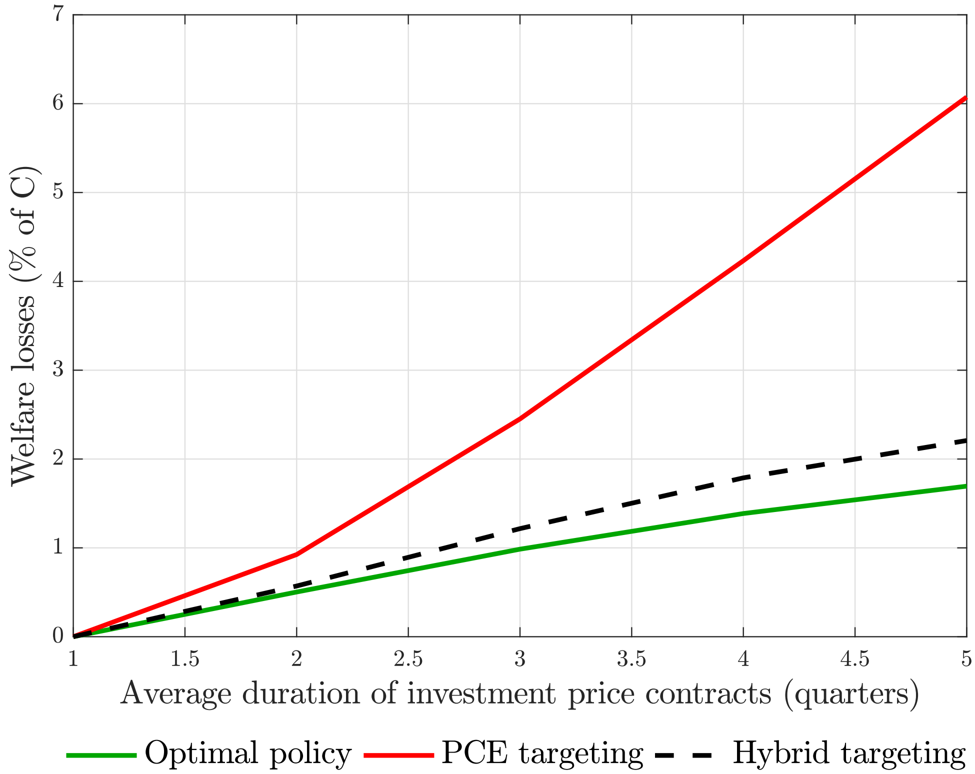


Figure 2.4: Welfare costs under alternative contract durations in the investment sector
Note: The average contract duration in the consumption sector is set equal to 4 quarters. Welfare losses are expressed as percent of steady-state consumption, multiplied by 100.

investment goods is plausibly at least as important as consumption goods price stickiness. This reinforces our message that central banks should, at a minimum, include investment-goods prices in their target inflation indexes.

2.6 Conclusions

Using a model calibrated to reproduce some important empirical features, we asked whether the optimizing monetary authority should target both consumption and investment price inflation. We found that in general the answer is yes, it should. In and of itself, this result may not be surprising. A variety of previous work suggests that in general monetary policy should target all prices that are imperfectly flexible. If investment-goods prices are sticky, then they should also feature in the inflation index that central banks target. The surprising element of our paper is the relative magnitudes of the costs of consumer versus investment price inflation. We find that welfare losses arising from markup variability in the investment sector are generally much larger than those that arise from similar variation in the consumption sector. This result stems from the fact that investment demand displays an almost infinite intertemporal elasticity of substitution, whereas intertemporal substitution of consumption over time is rather limited. Thus, predictable changes in investment-goods prices lead to large and sub-optimal fluctuations in the quantity of investment, leading to large social losses.

We find that monetary rules that target solely PCE inflation generate substantial welfare losses. These are considerably reduced, however, if the central bank includes investment price inflation as part of its inflation target. In particular, we show that a Taylor rule that responds to both consumer and investment price inflation can nearly replicate the best feasible outcome, provided that investment sector stabilization is assigned a significantly higher weight than the share of investment in GDP. For this reason, a GDP deflator targeting rule is better but still unsatisfactory. Furthermore, we show that our results hold for any plausible degree of nominal rigidity in the investment sector. Our results contrast with standard central banking practice, as monetary policy in most countries currently targets only consumer price inflation.

A fully satisfactory treatment of optimal monetary policy should take into account all three issues that are known to influence welfare losses from price rigidity: differences in the average duration of prices across sectors; differences in the degree of strategic complementarity within and across sectors, as emphasized by Carvalho (2006); and differences in the durability of sectoral outputs, which is our contribution to this discussion. This should be done in a framework that distinguishes at least four categories of output: non-durable consumption goods; durable consumption goods; equipment investment output; and the output of residential and non-residential structures. Fortunately, Basu et al. (2013) provide measures of technology for all four categories of final demand, so our exercise could be extended to an elaborate model of this type. We have not done so in order to explain our argument in a simple framework that can be explained intuitively and analyzed analytically. We leave this more disaggregated treatment for future research.

Chapter 3

Information Acquisition and Self-fulfilling Business Cycles

3.1 Introduction

In the presence of informational frictions, agents' learning effort over the business cycle may have profound implications for macroeconomic dynamics. The existing literature shows that the procyclicality of learning, or information available, can go a long way in explaining the occurrence of business cycle asymmetries, amplify shocks to fundamentals and rationalize the cyclical behavior of economic uncertainty.[1] Building on these insights, this paper shows that when agents optimally choose to acquire information procyclically, the macroeconomy may be subject to self-fulfilling fluctuations. That is, periods of expansions and recessions

[1] See, for example, Van Nieuwerburgh and Veldkamp (2006), and Hellwig and Veldkamp (2009).

occur solely as a result of changes in agents' expectations, as in the seminal work of Benhabib and Farmer (1994).

To this end, I study a real business cycle (RBC) economy that features monopolistic competition and firm-level uncertainty. In particular, each intermediate good producer cannot observe the realization of its idiosyncratic productivity shock at the price-setting stage, but can acquire a costly signal of finite precision about it. In my model, information acquisition is naturally procyclical because the benefit of more precise information – a lower average pricing error – is higher during periods of high aggregate demand. Thus, booms are associated with more precise information about firm-level fundamentals. Lower uncertainty, in turn, leads to a more efficient allocation of production factors across firms, and this reallocation effect leads to procyclical aggregate productivity and aggregate increasing returns to scale.[2] My main contribution is to show that a higher informational multiplier – a measure of the degree of returns to scale – exposes the economy to sunspot-driven fluctuations. In fact, to a first-order approximation the aggregate representation of this economy is isomorphic to the increasing-return economy in the classic paper by Benhabib and Farmer (1994). In their model with monopolistic competition, firm-level increasing returns generate an upward sloping labor demand curve that is the source of indeterminacy. In my alternative microfoundation, firm-level production functions display constant returns to scale and firm-level labor demand slopes downward, while the informational multiplier represents a shifter of firm-level labor demand (see Figure **??**). As shown by Basu and Fernald (1997),

[2] In my model, measured total factor productivity (TFP) contains an endogenous information factor.

the degree of firm-level increasing returns necessary to obtain sunspot-driven cycles in the Benhabib and Farmer economy are empirically implausible. For this reason, the procyclical information mechanism appears desirable in formalizing why self-fulfilling fluctuations may arise.

The predictions of my model are consistent with a number of empirical facts. First, the magnitude of increasing returns increases with the level of aggregation, in line with Basu and Fernald's (1997) evidence that estimates of returns to scale often rise at higher levels of aggregation. Second, my model conforms to Basu and Fernald's (2001) evidence that the reallocation of factors across uses with different marginal products is an important source of procyclical productivity. Third, my proposed mechanism hinges upon procyclical information acquisition, and resulting countercyclical firm-level uncertartainty. Using survey expectations data, Bachmann, Elstner and Sims (2013) find that business-level uncertainty tends to rise during recessions. Using plant-level data, Kehrig (2011) shows that the dispersion of revenue-based TFP in U.S. manufacturing – a measure of effective uncertainty in the model economy – is greater in recessions than in booms. As in David, Hopenhayn and Venkateswaran (2016), the model predicts that steady state output is decreasing in the cost of obtaining information. David, Hopenhayn and Venkateswaran (2016) convincingly argue that cross-country differences in information costs can go a long way in explaining the fact that misallocation accounts for a large fraction of cross-country differences in TFP (Hsieh and Klenow, 2009). Besides, in my model more costly information also leads to greater volatility of aggregate output as it implies a larger informational multiplier. This is consistent with the evidence that countries with lower mean growth experience larger growth volatility (see, e.g., Ramey and Ramey, 1995).

I show that self-fulfilling business cycles arise for a parameterization of my model that is consistent with several aggregate and cross-sectional moments, including the cross-sectional dispersion of firm-level revenue-based measures of TFP, and its standard deviation relative to output.[3] In addition, I estimate the aggregate version of my model using Bayesian techniques (Farmer, Khramov and Nicolò, 2015) and find that nonfundamental shocks account for around 30% of the fluctuations in key macroeconomic variables.

A growing literature has explored several implications of endogenous information acquisition in different classes of models. Reis (2006), Angeletos and Pavan (2007), Hellwig and Veldkamp (2009), Vives (2011), Colombo, Femminis and Pavan (2014), Benhabib, Liu and Wang (2016), and Chahrour and Gaballo (2017) study the role of information acquisition in static models.[4] A common theme across most of these papers is that information acquisition may generate multiple equilibria. The nature of this multiplicity is distinct from the one emphasized in this paper. In the aforesaid papers, multiple *static* equilibria arise because of complementarity in information acquisition. Instead, my model displays a unique steady state, in which costly precision gives rise to externalities (to other firms' profits and consumer surplus) that may generate multiple *dynamic* equilibria in a general equilibrium model of business cycles with otherwise standard features.[5] In business-cycle

[3] This parameterization refers to an extended version of the model with endogenous capital utilization.
[4] See also Pavan and Angeletos (2013) and Chamley (1986)
[5] In a unified game theoretical framework, Hellwig, Kohls and Veldkamp (2012) discuss which assumptions about the information choice technology are needed to generate increasing returns or multiple equilibria.

models, Llosa and Venkateswaran (2015) contrast the equilibrium acquisition of information with the efficient acquisition of information; Veldkamp and Wolfers (2007) show that complementarity in information acquisition rationalizes the observed synchronized expansions and contractions across sectors over the business cycle. In Van Nieuwerburgh and Veldkamp (2006) more economic activity generates more precise information about productivity, which makes business cycle downturns sharper than recoveries. Straub and Ulbricht (2015) propose a model where the ability of investors to learn about firm-level fundamentals declines after financial shocks, because actions of firms under financial distress carry less information and investors learn less about these firms' fundamentals. In the context of a rational-inattention model driven by time-varying, exogenous uncertainty shocks to idiosyncratic and aggregate productivity, Gondhi (2015) shows that when aggregate uncertainty increases resource misallocation arises because firms' managers allocate more information to aggregate shocks and less to idiosyncratic shocks. For the same reasoning, increases in idiosyncratic uncertainty generate an expansion. Senga (2015) study the effect of uncertainty shocks in a heterogenous firm model with Bayesan learning.[6] The paper closest to mine is the recent contribution by Benhabib, Liu and Wang (2016) with whom I share the key mechanism that links endogenous information acquisition to the reallocation of production factors. Their focus however is on explaining countercyclical idiosyncratic and aggregate uncertainty. My paper complements their work and those cited above by showing that

[6] In a model in which the equilibrium price system features endogenous information transmission, Mäkinen and Ohl (2015) show that firms have a stronger incentive to acquire information when the economy has been in a recession and a pessimistic belief about the state of the economy prevails than after a boom when firms share an optimistic belief.

information acquisition not only can amplify and propagate business cycle shocks, but can also generate dynamic indeterminacy and thus be a source of business cycles.

The recent financial crisis revived the interest in the literature on sunspot fluctuations. A number of papers have argued that sunspot fluctuations may stem because of various forms of financial frictions. In the context of a model with heterogeneous firms and imperfect contract enforcement, Liu and Wang (2014) show that a drop in equity value tightens credit constraints and reallocates resources from productive to unproductive firms, with the potential of generating dynamic indeterminacy. In their model, the source of reallocation and increasing returns is procyclical leverage.[7] Recently Benhabib, Dong and Wang (2014) show that adverse selection provides a microfoundation to the aggregate increasing returns to scale. I propose procyclical information acquisition as a complementary mechanism to those outlined above.

3.2 A RBC model with endogenous information acquisition

The model is written in continuous time.[8] The economy is populated by a large representative household that has a continuum of identical workers, with unit measure. The household holds the capital stock in the economy, derives utility from leisure and from consumption of a composite final good produced with a continuum of differentiated intermediate goods. In

[7] In a simple model, Benhabib and Wang (2013) show that procyclical leverage is the key features that allow financial-friction models to be indeterminate.

[8] Continuous time facilitates the stability analysis and the comparison with Benhabib and Farmer (1994).

each period, each intermediate-good producer is affected by both an idiosyncratic productivity shock and an aggregate productivity shock. While the aggregate shock is perfectly observable at the beginning of each period, each firm's information about its idiosyncratic productivity is limited and costly acquirable before the price-setting stage.

3.2.1 Households

The instantaneous utility of the representative household is given by:

$$\mathbb{U}(C_t, N_t) = \log C_t - \psi \frac{N_t^{1+\chi}}{1+\chi}$$

where C_t is consumption, N_t is labor supply, and $\chi \geq 0$. Taking the market interest rate R_t and wage W_t as given, the representative household maximizes

$$\int_0^\infty e^{-\rho t} \mathbb{U}(C_t, N_t) dt$$

subject to

$$\dot{K}_t = (R_t - \delta) K_t + W_t N_t - C_t \tag{3.1}$$

where K_t is the capital stock and K_0 is given. The parameter ρ represents the discount rate, and δ is the depreciation rate of capital.

The first-order conditions for the household's optimization problem are standard and given by

$$\frac{\dot{C}_t}{C_t} = r_t - \rho - \delta \tag{3.2}$$

$$\psi N_t^{\chi} = \frac{1}{C_t} W_t \tag{3.3}$$

3.2.2 Firms

Final Goods Producers

The final good is produced by competitive firms facing competitive factor markets under perfect information, according to the Dixit-Stiglitz aggregate production function:

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\theta-1}{\theta}} \mathrm{d}i \right]^{\frac{\theta}{\theta-1}} \tag{3.4}$$

for $\theta > 1$.

The profit-maximizing amount of input $Y_{i,t}$ is thus given by:

$$Y_{i,t} = P_{i,t}^{-\theta} Y_t \tag{3.5}$$

where aggregate demand movements act as shifters of the intermediate-good producer demand function, as usual in the context of Dixit-Stigliz monopolistic competition.

Intermediate Goods Producers

There is a representative, risk-neutral entrepreneur who owns a continuum of firms with unit mass. Entrepreneur's lifetime utility is given by:

$$\int_0^\infty e^{-\rho^e t} C_t^e dt$$

where ρ^e and C_t^e denote the representative entrepreneur's discount factor and time-t consumption, respectively. I assume that the entrepreneur is sufficiently less patient than the household so that the entrepreneur does not accumulate capital. Thus, entrepreneur's consumption consists solely of aggregate firm profits, in each time period.

Firm i is the monopolist of good i with production function:

$$Y_{i,t} = A_t A_{i,t} K_{i,t}^{\alpha} N_{i,t}^{1-\alpha} \tag{3.6}$$

Firm i produces $Y_{i,t}$ to maximize its profit under uncertainty about its own productivity $A_{i,t}$. Idiosyncratic productivity is determined according to:

$$\log A_{i,t} \equiv a_{i,t} = a + \epsilon_{i,t}$$

where $\epsilon_{i,t} \sim \mathcal{N}(0, \sigma_a^2)$. I assume that each firm has access to a signal $s_{i,t}$ about $a_{i,t}$ such that:

$$s_{i,t} = a_{i,t} + e_{i,t}$$

where $e_{i,t} \sim \mathcal{N}(0, \sigma_e^2)$.

Denote by $\tau_{e,i,t} \equiv 1/\sigma_e^2$ the precision of firm-i signal about its time-t productivity. To reduce uncertainty before price setting, firm i can spend $v(\tau_{e,i,t})$ units of the final good to acquire a signal $s_{i,t}$ of precision $\tau_{e,i,t}$.

Before proceeding with the problem of the intermediate-good firm it is useful to introduce the sequence in which events unfold within a time period:

Timeline of events At the beginning of each period, aggregate technology realizes, and, together with the beginning-of-period capital stock K_t, it is observed by all agents in the economy. The problem of the intermediate-good firm consists of three stages:

1. *Information choice.* After observing the aggregate state (A_t, K_t), each firm i chooses the precision $\tau_{e,i,t}$ of its signal $s_{i,t}$.

2. *Price setting.* After observing the signal $s_{i,t}$ of precision $\tau_{e,t}$, each firm sets its price $P_{i,t}$.[9]

3. *Production.* After observing the realization of its time-t productivity, each firm hires capital and labor and produces.

[9] Note that, since all firms are ex-ante identical, all choose the same signal precision during stage 1.

At the end of each period markets clear.

The model is solved backward. Stage 3 – firm-i cost-minimization problem under full information – implies:

$$W_t N(Y_{i,t}) + R_t K(Y_{i,t}) = \frac{1}{A_{i,t}} \frac{1}{A_t} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_t}{\alpha} \right)^{\alpha} Y_{i,t} \tag{3.7}$$

By looking at the right-hand side of Equation (3.7), one can notice that real marginal costs under perfect information consist of (the product of) a firm-specific and an aggregate component. Denote the latter by $C(W_t, R_t, A_t) \equiv \frac{1}{A_t} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_t}{\alpha} \right)^{\alpha}$.

While the input choice occurs under perfect information, the information set in Stage 2 – price setting – is limited to $\mathcal{I}^2_{i,t} = \{A_t, K_t, s_{i,t}\}$. Firm i profit-maximization problem reads:

$$\max_{P_{i,t}} \mathrm{E} \left[\left(P_{i,t} - \frac{1}{A_{i,t}} C(W_t, R_t, A_t) \right) P_{i,t}^{-\theta} Y_t \mid \mathcal{I}^2_{i,t} \right] \tag{3.8}$$

where I used Eqs. (3.5) and (3.7). The optimal price of firm i therefore is:

$$P_{i,t} = \frac{\theta}{\theta - 1} \mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right) C(W_t, R_t, A_t) \tag{3.9}$$

The optimal price consists of the product of the (constant) monopolistic markup and expected real marginal costs. Since aggregate variables are revealed by the aggregate state, expectation is formed solely about the idiosyncratic component of real marginal costs.

Before proceeding to Stage 1, it is useful to express the key aggregate variables as a function of signals precision. First, recall that under constant returns to scale production and perfect factor mobility the capital-labor ratio is identical across firms, i.e. $\frac{K_{i,t}}{N_{i,t}} = \frac{K_t}{N_t}$. Therefore, one can write the production function as: $Y_{i,t} = A_{i,t} A_t \left(\frac{K_t}{N_t}\right)^{\alpha} N_{i,t}$. As shown in Appendix C.1, by summing over i on both sides of the last equation, one obtains:

$$Y_t = \left(\int_0^1 \mathrm{E}_{i,t}\left(\frac{1}{A_{i,t}}\right)^{1-\theta} di\right)^{\frac{1}{\theta-1}} A_t K_t^{\alpha} N_t^{1-\alpha} \tag{3.10}$$

By using the process for idiosyncratic productivity and the information structure described above, Eq. (3.10) – the aggregate production function – can be rewritten as:

$$Y_t = \exp\left\{\tilde{a} + \frac{1}{2\tau_a}\theta\frac{1}{1+\frac{\tau_a}{\tau_{e,t}}}\right\} A_t K_t^{\alpha} N_t^{1-\alpha} \tag{3.11}$$

where $\tilde{a} = \bar{a} - \frac{1}{2}\sigma_a^2$. Equation (3.11) reveals that measured TFP features an endogenous component: more precise information reduces mispricing and thus renders the allocation of production factors across intermediate-good producers more efficient.

I now turn to Stage 1, that is I characterize the optimal information acquisition decision by the intermediate-good producer. One can show that firm-i realized profits after Stage 3 are:

$$\Pi_{i,t} = \left(P_{i,t} - \frac{1}{A_{i,t}}C\left(W_t, R_t, A_t\right)\right)Y_{i,t} = \frac{1}{\theta}Y_t\frac{\mathrm{E}_{i,t}\left(\frac{1}{A_{i,t}}\right)^{1-\theta}}{\int_0^1 \mathrm{E}_{i,t}\left(\frac{1}{A_{i,t}}\right)^{1-\theta} di} \tag{3.12}$$

I aim to find the value of signal precision for firm i, $\tau_{e,i,t}$, that is the best response to all other firms choosing $\tau_{e,-i,t}$.

By taking firm-i expectations of realized profits (Eq. 3.12) over all possible signal realizations, I obtain firm-i ex-ante expected profits:

$$\Pi^E_{i,t}\left(\tau_{e,i,t},\tau_{e,-i,t},Y_t\right)=\frac{1}{\theta}Y_t\frac{\exp\left\{(\theta-1)\left(\tilde{a}++\frac{1}{2\tau_a}\theta\frac{1}{1+\frac{\tau_a}{\tau_{e,i,t}}}\right)\right\}}{\exp\left\{(\theta-1)\left(\tilde{a}++\frac{1}{2\tau_a}\theta\frac{1}{1+\frac{\tau_a}{\tau_{e,-i,t}}}\right)\right\}} \tag{3.13}$$

Firm-i optimal signal precision satisfies:

$$\tau_{e,i,t}=\underset{\tau_{e,i,t}}{argmax}\quad \Pi^E_{i,t}\left(\tau_{e,i,t},\tau_{e,-i,t},Y_t\right)-v(\tau_{e,i,t}) \tag{3.14}$$

The first-order condition to the above problem is given by:

$$\frac{\partial\Pi^E_{i,t}(\cdot)}{\partial\tau_{e,i,t}}=\frac{\partial v(\tau_{e,i,t})}{\partial\tau_{e,i,t}} \tag{3.15}$$

which states that, at an optimum, the marginal benefit of information acquisition – higher ex-ante expected profits – equalizes its marginal cost.

The following Lemma states the conditions under which Eq. (3.15) fully characterizes a unique solution for firm-i information acquisition problem.

Lemma 1 *Given aggregate variables, firm-i ex-ante expected profit is strictly increasing in signal precision, that is* $\frac{\partial\Pi^E_{i,t}(\cdot)}{\partial\tau_{e,i,t}}>0$. *If* $\tau_a>\frac{1}{4}\theta(\theta-1)$, *then the expected profit function is also strictly concave on the whole domain of* $\pi^E_{i,t}(\cdot)$, *that is* $\frac{\partial^2\pi^E_{i,t}(\cdot)}{\partial\tau^2_{e,i,t}}<0$. *Under this assumption, and the (weak) convexity of the cost function* $v(\tau_{e,i,t})$, *firm-i information acquisition problem* *has a unique solution which can be fully characterized by Eq. (3.15).*

Next, I introduce a functional form for the function that governs the cost of acquiring information, $v(\tau_{e,i,t})$:

Assumption 1 *The function that describes the cost of acquiring information is given by:*

$$v(\tau_{e,i,t}) = \phi \left(\frac{\tau_{e,i,t}}{\tau_a} + 1 \right)^{\zeta} \tag{3.16}$$

where $\phi > 0$ and $\zeta \geq 1$.

where the parameter ϕ governs the efficiency of the cost function, and ζ captures the cost elasticity of information. One can notice that the cost function in Equation (3.16) satisfies the conditions in Lemma 1 (weak convexity). Note also that, when $\zeta = 1$, Equation (3.16) corresponds to the cost function almost exclusively used in the rational inattention literature (e.g. Mackowiak and Wiederholt (2009)).[10]

Since all firms are ex-ante identical, they will all make the same information acquisition decision (i.e. $\tau_{e,i,t} = \tau_{e,-i,t} = \tau_{e,t}$). Thus, invoking symmetry and using Eqs. (3.13) and (3.16), Eq. (3.15) becomes:

[10] More specifically, denote by κ_t the endogenous information-processing capacity of an agent. Under the rational inattention paradigm, the information flow constraint of an agent is

$$\mathcal{I}\left(\{A_{i,t}\}; \{s_{i,t}\}\right) = \frac{1}{2} \log_2 \left(\frac{\tau_{e,t}}{\tau_a} + 1 \right) = \kappa_t$$

where the information flow is measured in terms of reduction in conditional entropy. Equation (3.16) is equivalent to a capacity cost function that reads:

$$f(\kappa_t) = \phi \left(2^{2\kappa_t}\right)^{\zeta}$$

$$\frac{1}{2}(\theta - 1)Y_t = \phi\zeta\tau_a \left\{ \frac{\tau_{e,t}}{\tau_a} + 1 \right\}^{\zeta+1} \tag{3.17}$$

Equation (3.17) describes the optimal information choice as a function of aggregate output. Higher aggregate output is unambiguously associated with lower uncertainty, as firms will choose to acquire more precise signals about their idiosyncratic state. Optimal information acquisition is procyclical because the marginal benefit of more precise information – higher ex-ante expected profits (see Eq. 3.15) – is higher during booms; in fact, more precise information increases ex-ante expected profits because it reduces the losses from mispricing. These losses are increasing in the scale of the firm (see Eq. 3.13), which is directly associated with aggregate output because of monopolistic competition (see Eq. 3.5). Since the marginal cost of information acquisition is acyclical, optimal information acquisition is procyclical.

3.2.3 Equilibrium

The formal definition of equilibrium in the baseline model is as follows.

The Rational Expectations Equilibrium (REE) in this economy is a sequence of aggregate allocations $\{C_t, N_t, Y_t, K_t, \Pi_t, \tau_{e,t}\}$, individual productions $Y_{i,t}$ for intermediate firms, and prices $\{W_t, R_t, \{P_{i,t}\}\}$, such that for each realization of A_t, (i) C_t, N_t, and K_t maximize households' utility given the equilibrium prices W_t and R_t; (ii) Eq. (3.5) maximizes the final goods firm's profit given equilibrium prices $\{P_{i,t}\}$; (iii) given W_t, R_t and signals $s_{i,t}$, $Y_{i,t}$ maximizes the expected profits for an intermediate firm; (iv) $\tau_{e,t}$ solves the representative entrepreneur's problem by maximizing aggregate profits; and (v) all markets clear, namely,

$$\dot{K} = \frac{\theta - 1}{\theta} Y_t - \delta K_t - C_t \tag{3.18}$$

$N_t = \int_0^1 N_{i,t} \mathrm{d}i$ and $K_t = \int_0^1 K_{i,t} \mathrm{d}i$ also hold. The equilibrium conditions are thus given by:

$$\frac{\dot{C}_t}{C_t} = \frac{\theta - 1}{\theta} \alpha \frac{Y_t}{K_t} - \rho - \delta \tag{3.19}$$

$$\dot{K}_t = \frac{\theta - 1}{\theta} Y_t - \delta K_t - C_t \tag{3.20}$$

$$\psi N_t^{\chi} C_t = \frac{\theta - 1}{\theta} (1 - \alpha) \frac{Y_t}{N_t} \tag{3.21}$$

$$Y_t = \exp \left\{ \theta \frac{1}{2\tau_a} \frac{\tau_{e,t}}{\tau_{e,t} + \tau_a} \right\} A_t K_t^{\alpha} N_t^{1-\alpha} \tag{3.22}$$

$$\frac{1}{2}(\theta - 1) Y_t = \phi \zeta \tau_a \left\{ \frac{\tau_{e,t}}{\tau_a} + 1 \right\}^{\zeta + 1} \tag{3.23}$$

The equilibrium conditions (3.19)-(3.21) coincide with those that arise from a standard RBC model with monopolistic competition. As discussed above, Eq. (3.22) reveals that measured TFP contains an endogenous component that depends upon the amount of uncertainty in the model economy, and Eq. (3.23) describes the optimal information acquisition decision as a function of aggregate output.

The baseline model is one parameter away from a standard RBC model with monopolistic competition (and idiosyncratic shocks). In fact, if information acquisition is costless ($\phi = 0$), and thus uncertainty is nil ($\tau_{e,t} = \infty$, by Eq. (3.23)), Eq. (3.22) collapses to a standard, exogenous-TFP production function.

3.2.4 Steady State

I state the conditions for the existence and uniqueness of a steady-state equilibrium, and observe that steady states with more costly information are associated with lower output and measured TFP.

Lemma 2 *(Existence and uniqueness of steady-state equilibrium) Assume that the output elasticity of capital in the aggregate production function is less than one (i.e., $\gamma\alpha < 1$, where γ denotes the degree of returns to scale in the aggregate production function). Also, assume that $\phi < \phi^*$, and that τ_a is sufficiently large. Then, a unique steady-state equilibrium exists.*

Proof. Evaluate the system of equations (3.19)-(3.23) in steady state. As usual, Eq. (3.19)-(3.21) reveal that Y/K, Y/C and N are constant in a steady-state equilibrium. By using these values into the aggregate production function (Eq. (3.22)), one can write Y as a function of τ_e and parameters. That is,

$$Y = \mathcal{Y}(\tau_e, \cdot) = \exp\left\{\theta \frac{1}{2\tau_a} \frac{\tau_e}{\tau_e + \tau_a}\right\} A \left(\frac{\theta-1}{\theta} \frac{\alpha}{\rho+\delta}\right)^{\alpha} \left[\frac{\theta-1}{\theta} \frac{1-\alpha}{\Psi} \left(\frac{\theta-1}{\theta} \left(\frac{\rho+\delta-\alpha\delta}{\rho+\delta}\right)\right)\right]^{\frac{1-\alpha}{1+\chi}}$$

Together with the last equation, Eq. (3.23) in steady state implies that one can obtain an equation that defines τ_e implicitly. It is useful to write this as:

$$\phi = \mathcal{T}(\mathcal{Y}(\tau_e, \cdot), \tau_e, \cdot) \tag{3.24}$$

Note that $\mathcal{T}(\mathcal{Y}(0, \cdot), 0, \cdot) \equiv \phi^* > 0$, and $\mathcal{T}(\mathcal{Y}(\infty, \cdot), \infty, \cdot) = 0$. Given the continuity of $\mathcal{T}(\cdot)$, the intermediate value theorem implies that at least one solution exists. Furthermore, note that $\mathcal{T}_{\tau_e}(\mathcal{Y}(0, \cdot), 0, \cdot) < 0$ on the whole domain of τ_e as long as $\tau_a > \frac{1}{2}\frac{\theta}{1+\zeta}$. Thus, the steady-state equilibrium exists and is unique under the conditions stated in the Lemma. ■

Lemma 3 *(David, Hopenhayn and Venkateswaran (2016)) Steady-state output and measured TFP are decreasing functions of ϕ.*

Thus, economies where steady-state uncertainty is higher (higher ϕ or, equivalently, lower τ_e) feature higher misallocation of factors of production, and hence lower steady state TFP and output.

3.2.5 Log-linear equilibrium

I solve the model by taking a log-linear approximation of the equilibrium conditions around its steady state. These read:

$$\dot{c}_t = (\rho + \delta)(y_t - k_t) \tag{3.25}$$

$$y_t = (1 + \chi)n_t + c_t \tag{3.26}$$

$$\dot{k}_t = \delta k_t + \frac{\rho + \delta}{\alpha} y_t - \frac{\rho + (1-\alpha)\delta}{\alpha} c_t \tag{3.27}$$

$$y_t = \left(\frac{1}{2}\theta\mathbb{V}\right) \underbrace{\frac{\tau_e}{\tau_e + \tau_a}\hat{\tau}_{e,t}}_{-\hat{\mathbb{V}}_t} + (a_t + \alpha k_t + (1-\alpha) n_t) \tag{3.28}$$

$$\underbrace{\frac{\tau_e}{\tau_e + \tau_a}\hat{\tau}_{e,t}}_{-\hat{\mathbb{V}}_t} = \left(\frac{1}{1+\zeta}\right) y_t \tag{3.29}$$

where $\mathbb{V}_t = \frac{1}{\tau_{e,t} + \tau_a}$ denotes the posterior variance of $a_{i,t}$, and is interpretable as the amount of time-t uncertainty faced by intermediate-good producers in the model economy.

3.3 Information acquisition, aggregate increasing returns, and indeterminacy

In this section, I show that micro-level uncertainty, together with endogenous information acquisition, is equivalent to a representative-firm economy with increasing returns. To this end, substitute Eq. (3.29) into Eq. (3.28), and obtain the (log-linearized) reduced-form aggregate production function:

$$y_t = \gamma(a_t + \alpha k_t + (1-\alpha) n_t) \tag{3.30}$$

where $\gamma = \frac{1}{1 - \frac{1}{2}\theta\frac{\mathbb{V}}{1+\zeta}}$ denotes the degree of returns to scale in the aggregate production function.

Note that both imperfect information and endogenous information acquisition are necessary ingredients in order for the production function to exhibit increasing returns to scale. In fact, under perfect information (i.e. $\phi = 0$), uncertainty in the model economy would be zero in the steady state (and at all times), and the aggregate production function would feature constant returns to scale ($\gamma = 1$). Moreover, *endogenous* information acquisition is also necessary to obtain increasing returns. If information is imperfect ($\phi > 0$) but adjusting a firm's degree of information is infinitely costly ($\zeta = \infty$), the procyclical productivity mechanism that is conducive to aggregate increasing returns would not be at play and the economy would display a constant returns to scale aggregate production function ($\gamma = 1$). In light of these observations, I refer to γ as the "informational multiplier" of the model economy, and summarize the aforesaid result in the next proposition.

Proposition 2 *The reduced-form aggregate production function in the model economy exhibits increasing returns if and only if there is a positive informational multiplier (i.e., $\gamma > 1$)*

It is well known, at least since the seminal work of Benhabib and Farmer (1994), that the equilibrium of economies with increasing returns to scale production functions are prone to be dynamically indeterminate. The following proposition states the conditions under which endogenous information acquisition gives rise to equilibrium indeterminacy – and hence the economy is prone to self-fulfilling fluctuations.

Proposition 3 *Assume that the output elasticity of capital in the aggregate production* *function is less than one (i.e., $\gamma\alpha < 1$). The necessary and sufficient condition for equilibrium indeterminacy in the benchmark economy is given by*

$$\gamma > \frac{1+\chi}{1-\alpha}$$

Proof. See Benhabib and Farmer (1994). ■

The last proposition states that a higher informational multiplier exposes the economy to self-fulfilling fluctuations, because it enhances the two-way interaction between aggregate output and uncertainty. To gain further intuition, it is useful to compare the information-acquisition economy to the representative-firm economy with monopolistic competition and increasing returns of Benhabib and Farmer (1994). First, note that while the two economies feature a mathematically isomorphic aggregate representation, they substantially differ in the micro foundations that lead to aggregate increasing returns. Indeed, in the monopolistic-competition economy of Benhabib and Farmer (1994), the parameter γ captures the degree of *firm-level* returns to scale, whereas in the information acquisition economy all firms produce under constant returns to scale, and the information-acquisition-induced procyclical productivity leads to *aggregate* increasing returns. To conclude the comparison with Benhabib and Farmer (1994) and the earlier literature, it is useful to rewrite the indeterminacy condition of my model as follows:

Corollary 1 *The indeterminacy condition in Proposition 3 is equivalent to:*

$$\underbrace{\frac{1}{1+\zeta}}_{\epsilon_{\mathbb{V}_t,Y_t}} > \left(\frac{1}{2}\theta\frac{1+\chi}{\chi+\alpha}\mathbb{V}\right)^{-1} \tag{3.31}$$

The left-hand side represents the elasticity of uncertainty (or information acquisition) to changes in aggregate output. The condition in Equation (3.31) states that the responsiveness of information to output fluctuations should be sufficiently high for the economy to display output fluctuations.

3.4 Empirical plausibility of self-fulfilling fluctuations

I have shown that, to a first-order approximation, the model with endogenous information acquisition is observationally equivalent to a representative-agent economy with firm-level increasing returns (Proposition 2). Further, I have shown that the economy is potentially prone to self-fulfilling fluctuation, provided that the informational multiplier, γ, is sufficiently large (Proposition 3). I now investigate the empirical plausibility of self-fulfilling business cycles in an extended version of the model with variable capacity utilization.

3.4.1 The model with variable capital utilization

Wen (1998) shows that variable capital utilization leads to indeterminacy in the Benhabib and Farmer's model for mild levels of increasing returns. I model endogenous capacity utilization along the lines of Greenwood, Hercowitz and Huffman (1988) by assuming that households choose the capacity utilization rate U_t. As a result, the total effective capital available for production is $U_t K_t$. A higher U_t implies that capital is more intensively utilized, at the cost of faster depreciation (thus $\delta(U_t)$, defined below, is a convex increasing function). The household's budget constraint (3.1) becomes

$$\dot{K}_t = (R_t U_t - \delta(U_t))K_t + w_t N_t - C_t \tag{3.32}$$

The capital depreciation rate varies with capacity utilization according to

$$\delta(U_t) = \delta_0 \frac{U_t^{1+\eta}}{1+\eta} \tag{3.33}$$

where $\delta_0 \in (0,1)$ is a constant and $\eta > 0$ measures the elasticity of the depreciation rate with respect to capacity utilization. The household's optimizing choices now include an additional endogenous variable – the capacity utilization rate U_t.

The next proposition shows that the effect of the information multiplier is now amplified due to the introduction of variable utilization.

Proposition 4 *(Wen, 1998) In the extended model with variable capacity utilization, a 1 percent change in TFP holding input factors constant results in $\tilde{\gamma}$ percent change in aggregate output, where*

$$\tilde{\gamma} \equiv \frac{d \log Y_t}{d \log A_t} = \frac{1+\eta}{1+\eta-\alpha\gamma}\gamma > \gamma$$

Thus, as shown by Wen (1998), capacity utilization has a positive effect on the aggregate returns to scale.[11] As a result, variable capacity utilization makes indeterminacy more likely, ceteris paribus.

3.4.2 Parameterization

I set $\rho = 0.01$, so the quarterly discount factor $\beta = 1/(1+\rho) = 0.99$. I follow Hansen (1985) and Rogerson (1988) and assume infinitely elastic labor supply ($\chi = 0$). The factor share of capital is $\alpha = 1/3$. I set $\eta = 0.35$, in line with available estimates. I set $\delta = 0.033$ which is consistent with an average lifetime of new equipment of about 30 quarters.[12] I set $\theta = 8$ which implies an average steady-state markup of about 1.14, in line with estimates by Basu and Fernald (1997).[13] I set $\zeta = 1$, so that the information cost function corresponds to the one commonly adopted in the rational inattention literature (see, for example, Mackowiak and Wiederholt, 2009). To parametrize the steady-state distribution of idiosyncratic shocks, governed by σ_a^2, and the information cost ϕ (or, equivalently, the degree of uncertainty in the steady state $\mathbb{V}$), I adopt the following strategy. Following Foster, Haltiwanger and Syverson (2008) and Hsieh and Klenow (2009), define quantity-based TFP and revenue-based TFP of firm i respectively as:

$$\log(TFPQ_i) \equiv a_i \qquad \log(TFPR_i) \equiv p_i - \bar{p} + a_i$$

and notice that, in my model:

[11] This is often referred to as the "returns to scale effect" of capital utilization

[12] As a result $\delta_0 = 0.0462$, which implies $U = 1$ in steady state.

[13] The preference parameter ψ is calibrated to obtain steady-state hours worked $N = 0.3$.

$$\mathrm{Var}_i\left(\log(TFPQ_i)\right) = \sigma_a^2 \qquad \mathrm{Var}_i\left(\log(TFPR_i)\right) = \mathbb{V}$$

I resort to within industry-year estimates from Hsieh and Klenow (2009) for the U.S., and set $\sigma_a^2 = 0.1560$ and $\mathbb{V} = 0.0420$.[14]

The above parametrization implies that $\gamma = 1.092$, in line with Basu and Fernald's (1997) evidence that returns to scale are around 1.10 in the manufacturing sector. Besides, the fundamental uncertainty eliminated from private learning $\left(\frac{\mathbb{V}-\sigma_a^2}{\sigma_a^2}\right)$ is about 73%. David, Hopenhayn and Venkateswaran (2016) estimate it to be between 30% and 60%. Steady-state information capacity is around 1 bit. Landauer (1986) estimated that individuals process about 2 bits per second in the laboratory. The relative standard deviation of uncertainty, or $TFPR$ dispersion is 0.5. Kehrig (2011) estimates $TFPR$ dispersion to be around 0.9 for durables and and around 1.7 for non-durables. If the model were to parameterized to match these estimates, self-fulfilling fluctuations would be more likely relative to the baseline.[15] Under the baseline parameterization, the condition in Proposition 4 is satisfied. The model's dynamic equilibrium is therefore indeterminate, and self-fulfilling business cycles are possible.

[14] I apply appropriate transformations to obtain quarterly figures from Hsieh and Klenow's (2009) annual estimates.

[15] Note that the model-implied expected profit loss from mispricing are relatively high. These, as a share of revenues, are given by

$$\frac{(\theta-1)}{2}\,\mathrm{E}\left(P_{i,t}^{*} - P_{i,t}\right)^2 = \frac{(\theta-1)}{2}\mathbb{V} \approx 14\%$$

Zbaracki et al. (2004) estimate these to be around 1.22% of revenues. The discrepancy between the model and the data along this dimension is due to the model's simplicity: all mispricing, and resulting misallocation, in the model are due to idiosyncratic uncertainty. A richer model – featuring other sources of misallocation – would likely bring the expected profit loss from mispricing closer to available estimates.

3.4.3 Empirical estimation of aggregate model

A discrete-time version of the extended aggregate model with TFP shocks is estimated using Bayesian techniques (see Herbst and Schorfheide, 2016). TFP is assumed to follow the autoregressive process in logs:

$$\log(A_t) = \rho_A \log(A_{t-1}) + \varepsilon_{A,t}$$

where $\varepsilon_{A,t}$ are i.i.d. disturbances drawn from a Normal distribution with mean zero and standard deviation σ_A. As I estimate the model economy in its indeterminacy region, the dynamic equilibrium is not unique, and I introduce sunspots to select the equilibrium. I follow the insight of Farmer, Khramov and Nicolò (2015) in specifying an expectation error to consumption as a new exogenous shock:

$$c_t = E_{t-1} c_t + \eta_{c,t}$$

The expectation error, $\eta_{c,t}$, is allowed to be influenced by both fundamental and nonfundamental shocks:

$$\eta_{c,t} = \omega_A \varepsilon_{A,t} + \varepsilon_{s,t}$$

where ω_A governs the influence of technology innovations on the expectation error of consumption, while $\varepsilon_{s,t}$ are i.i.d. disturbances drawn from a Normal distribution with mean zero and standard deviation σ_S. I refer to these shocks as sunspots as they are independent of fundamentals.

The observable variables that I use in the estimation are U.S. output, consumption, investment, and hours worked from 1947:1 to 2015:4.[16,17]

Prior				Posterior	
Name	Density	Mean	Std. Dev.	Mean	90% interval
γ	Beta	1.3	0.1	1.65	[1.57, 1.72]
ρ_A	Beta	0.8	0.1	0.87	[0.84 0.91]
σ_A	Inverse gamma	0.5	Inf	0.21	[0.19 0.23]
ω_A	Uniform	0	3	0.55	[0.48 0.61]
σ_s	Inverse gamma	0.5	Inf	0.42	[0.35 0.49]

Table 3.1: Prior and posterior distributions for model parameters

The parameters of the extended aggregate economy that are estimated are the reduced-form informational multiplier γ, the persistence and standard deviation of the shock to aggregate TFP (ρ_A and σ_A), the standard deviation of the sunspot shock (σ_s), and the co-variance between the expectational error and the fundamental shock, ω_A. Table 3.1 reports the shape of the priors. I assume a beta distribution for γ with a lower limit that ensures that the model remains in the indeterminate region. I assume a largely uninformative uniform distribution for ω_A. The choice of the priors for the other parameters follow common practice in the literature. I obtain 500,000 draws from the posterior mean for each of the five chains using a Metropolis-Hastings algorithm. I adjust the scale in the jumping distribution to achieve a 25% acceptance rate for each chain. The resulting posterior distribution of es-

[16] I filter out the trend components of these variables using a one-sided HP filter.
[17] To avoid stochastic singularity, I add two measurement error shocks (to output and hours worked)

timated parameters, reported in Table 3.1, indicates that these are estimated with precision and are within empirically plausible ranges, except for the degree of aggregate returns to scale which appears relatively high. In Figure C.2.1 in Appendix C.2, I follow Pavlov and Weder (2017) in comparing the estimated series for the sunspot shock to a commonly used index for U.S. consumer confidence. The fluctuations in the two series is remarkably similar, suggesting that the estimated sunspot shocks are (at least partially) capturing so-called consumers' sentiment. That said, I note that consumer confidence indexes are endogenous and thus likely reflects consumers' expectations as a function of fundamental shocks.

Equilibrium dynamics following a sunspot shock and variance decomposition

Figure 3.1 reports the impulse responses of the estimated model to a one standard deviation sunspot shock. A positive realization of the sunspot leads to a persistent increase of all macroeconomic aggregates, as well as a reduction in micro-level uncertainty - due to the procyclical information acquisition.

Table 3.2 reports the unconditional variance decomposition implied by the estimated model. The estimation attributes around 70% of macroeconomic fluctuations to fundamental shocks, while around 30% to nonfundamental shocks. An extended version of this model with more than two structural shocks would be desirable to further decompose the sources of business cycles.

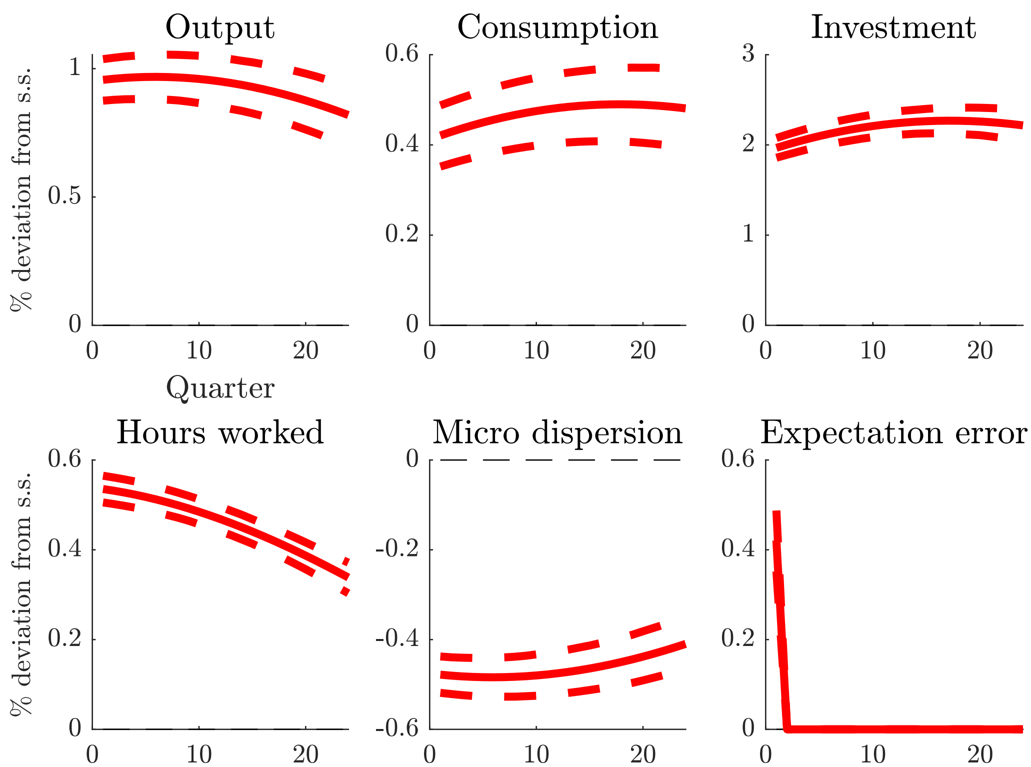


Figure 3.1: Impulse responses to a sunspot shock from estimated model
Note: The solid lines represent the estimated actual mean responses. Dashed lines represent the 10 percent and 90 percent posterior interval. Micro dispersion refers to the posterior variance $\mathbb{V}$.

	Output	Consumption	Investment	Hours
Technology shocks	70%	71%	69%	69%
Sunspot shocks	30%	29%	31%	31%

Table 3.2: Unconditional variance decomposition

3.5 Conclusions

Measures of firm-level productivity dispersion tend to increase during recessions (Kehrig, 2011), periods in which measured aggregate productivity tends to decline (Basu and Fernald, 2001). In this paper, I interpreted these comovements as the equilibrium of a RBC model with idiosyncratic uncertainty and endogenous information acquisition. In particular, I find that this model displays aggregate increasing returns to scale and indeterminacy of its dynamic equilibrium becomes a possibility, as in Benhabib and Farmer (1994). I show that this possibility is empirically plausible as indeterminacy arises in a model parameterized to replicate a set of moments of the distribution of firm-level productivity. A Bayesian estimation of the model suggests that non-fundamental shocks explain a significant fraction of aggregate fluctuations. Endogenous uncertainty thus appears to be a plausible mechanism behind aggregate increasing returns to scale and business cycle fluctuations.

Appendix A

International Spillovers and the Exchange Rate Channel of Monetary Policy

A.1 Dataset

- Nominal exchange rates (s_t, monthly): the preferred measure of exchange rates are official exchange rates. If these are not available, we use period average market rates, or period average principal exchange rates. The main data source is the International Financial Statistics (IFS) compiled by the International Monetary Fund (IMF).

- Policy-controlled interest rates (r_k, monthly): These rates are measured in the data as the period average T-bill rates, the closest to the overnight interbank lending rates. If these are not available, discount rates, or money market rates are used. The main data source is the International Financial Statistics (IFS) compiled by the

International Monetary Fund (IMF).

- U.S. policy-controlled interest rates ($r^\star$, monthly): This rate is measured by the Federal Funds rate.

- Exchange rate regimes: these are determined according to the historical exchange rate classification in Reinhart and Rogoff (2004), recently updated by Ilzetzki, Reinhart and Rogoff (2017). A country is deemed to have a flexible exchange rate regime if, in a given year, its exchange rate was either (i) within a moving band that is narrower than or equal to +/-2 percent; or (ii) was classified as managed floating; or (iii) was classified as freely floating; or (iv) was classified as freely falling in Reinhart and Rogoff (2004). For countries that had multiple episodes of flexible exchange rates during this period, we follow Hnatkovska, Lahiri and Vegh (2016) in considering each episode separately subject to the restriction that there were at least 24 months of data in each episode.

- U.S. industrial production (monthly):

- U.S. CPI inflation (monthly):

- Chicago Board Options Exchange Volatility Index (VIX, monthly):

- Net foreign asset positions to GDP (annual): Updated and extended version of dataset constructed by Lane and Milesi-Ferretti (2007).

- Data used for information sufficiency test (monthly): To be written up.

- List of countries in the dataset: See Table A.1.1.

Country	Time period	Country	Time period
Albania	1994:7-2001:12	Algeria	1988:1-1995:1
Angola	2002:1-2005:5	Australia	1974:1-2010:11
Austria	1974:1-1998:12	Belarus	1994:1-2002:10
Belgium	1974:1-1998:12	Brazil	1999:2-2007:12
Canada	1974:1-2010:11	Chile	1999:9-2001:12
China, P.R. (Mainland)	1990:3-1992:7	Congo, Dem. Rep. of	1994:7-2004:2
Costa Rica	1980:10-1983:10	Czech Republic	1997:6-2001:12
Denmark	1981:5-1988:12	Dominican Republic	2003:11-2007:12
Euro Area	1999:1 - 2010:11	Finland	1974:1-1998:12
France	1974:1-1998:12	Gambia, The	1986:1-1991:9
Germany	1975:7-1998:12	Ghana	1985:4-2001:3
Greece	1983:1-2000:12	Haiti	1994:10-2007:12
Iceland	1987:6-2010:11	Indonesia	1997:8-2007:12
Ireland	1974:1-1998:12	Italy	1977:3-1998:12
Jamaica	1990:10-1992:12	Japan	1974:1-2010:11
Kazakhstan	1994:4-1996:5	Kenya	1987:1-1995:12
Korea, Rep. of	1997:12-2007:12	Kyrgyz Republic	1994:1-1999:11
Lao People S Dem. Rep.	1997:9-2000:3	Lebanon	1984:3-1991:7
Luxembourg	1990:1-1998:12	Madagascar	2002:10-2007:12
Malawi	1983:1-1994:12	Malawi	1997:8 - 2003:8
Malta	1987:11-2000:12	Mexico	1982:2-1988:11
Mexico	1995:1-2007:12	Netherlands	1974:1 - 1990:8
New Zealand	1978:1-2010:11	Nigeria	1991:7-2007:12
Norway	1974:1-2009:5	Peru	1990:1-1993:10
Philippines	1997:7-1999:11	Portugal	1982:4 -1998:5
Romania	1994:3 -2001:3	Serbia, Rep. of	2003:3-2007:12
Sierra Leone	2002:1-2005:6	Singapore	1974:1-2007:12
South Africa	1974:1-1985:8	South Africa	1995:3-2007:12
Spain	1979:1-1998-12	Sweden	1974:1-2010:11
Switzerland	1980:1-2010:11	Syrian Arab Rep.	1982:6-1987:12
Tajikistan	1998:10-2002:10	Thailand	2001:2-2007:12
Turkey	2001:2-2007:12	Uganda	1980:1-1986:8
Ukraine	1992:12-1996:9	United Kingdom	1974:1-2010:10
Uruguay	1991:12-1995:9	Uruguay	2002:5-2005:5
Zambia	1978:1-1983:7	Zambia	1985:11-2007:12

Table A.1.1: Sample used in the empirical work

A.2 Additional results from empirical analysis

A.2.1 Granger causality test

We perform a test of Granger causality that consists in regressing the Federal Funds rate on up to 36 lags of the identified monetary policy shock. The null of no Granger causality is rejected if the coefficients associated with the lags of the monetary policy shock series are jointly significant. Table A.2.1 shows the p-values of the F-statistic of a regression that includes up to 36 lags of the monetary policy shock series for each of the largest countries in our sample. The monetary policy shock identified through recursive ordering appears to systematically predict future movements in the Federal Funds rate, especially when longer horizons are part of the regression. Specifically, we reject the null of no Granger causality in all countries at 5% level of significance with the exception of South Africa and Brazil. Somewhat similar figures appear when we perform the Granger causality test using the cyclical component of U.S. industrial production.

	Federal Funds rate			U.S. industrial prod.		
	1 lag	12 lags	36 lags	1 lag	12 lags	36 lags
Industrial countries						
Germany	0.00	0.00	0.31	0.00	0.00	0.00
Canada	0.00	0.00	0.00	0.00	0.00	0.01
Italy	0.03	0.60	0.93	0.06	0.05	0.00
France	0.00	0.00	0.00	0.00	0.00	0.00
Japan	0.02	0.01	0.04	0.20	0.54	1.00
United Kingdom	0.01	0.00	0.00	0.09	0.00	0.01
Developing countries						
Indonesia	0.93	0.00	0.00	0.83	0.01	0.39
Brazil	0.98	1.00	0.86	0.98	0.04	0.81
South Africa	0.92	0.99	0.22	0.73	0.99	1.00
Korea	0.88	0.46	0.00	0.21	0.60	0.83
Mexico	1.00	1.00	0.00	0.86	1.00	0.40
Philippines	0.70	0.03	-	0.87	0.69	-

Table A.2.1: Granger causality test

Notes: The table reports the p-values of the F-statistic of a regression of Federal Funds rate and HP-filtered U.S. industrial production on up to 36 lags of the monetary policy shock series for each country. The p-value for Philippines is not reported for 36 lags because of its limited sample size.

A.2.2 Information sufficiency test

Is the identified anticipated external shock predictable? That is, is the informational content in the baseline VAR sufficient to identify the anticipated external shock? Following Forni and Gambetti (2014), we test the null of informational sufficiency of the VAR to recover the anticipated external shock. The test is implemented as follows. We begin by computing the principal components of large data set that captures all the relevant U.S. macroeconomic information, described in Appendix A.1. For each country, we test whether the first h principal components, where $h = 1, \ldots, 5$, Granger cause the identified anticipated external shock, $\varepsilon_t^{\star\star}$. We include four lags of each principal component. If the null of no Granger causality is never rejected, $\varepsilon_t^{\star\star}$ is informationally sufficient. Otherwise, information sufficiency is rejected.

Table A.2.2 shows the p-value of the F-test statistics for the largest economies in our sample. We include 1, 3, and 5 principal components. We fail to reject the null of informational sufficiency at 5% level of significance in all countries.

	P-value of F-statistic						
	Industrial countries				Developing countries		
	P.C. =1	*P.C. = 3*	*P.C. =5*		*P.C. =1*	*P.C. = 3*	*P.C. =5*
Germany	0.27	0.51	0.61	Indonesia	0.99	0.99	1.00
Canada	0.24	0.57	0.68	Brazil	0.72	0.97	0.87
Italy	0.21	0.17	0.33	South Africa	0.42	0.82	0.44
France	0.88	0.93	0.47	Korea	0.09	0.36	0.10
Japan	0.30	0.19	0.22	Mexico	0.74	0.52	0.55
United Kingdom	0.83	0.81	0.47	Philippines	0.80	0.97	0.82

Table A.2.2: Information sufficiency test

Notes: The table reports the p-values of the F-statistic of a regression of the identified anticipated external shock on up to 5 principal components (P.C.) of a large data set capturing all the relevant U.S. macroeconomic information, described in Appendix A.1.

A.2.3 Forecast error variance decomposition

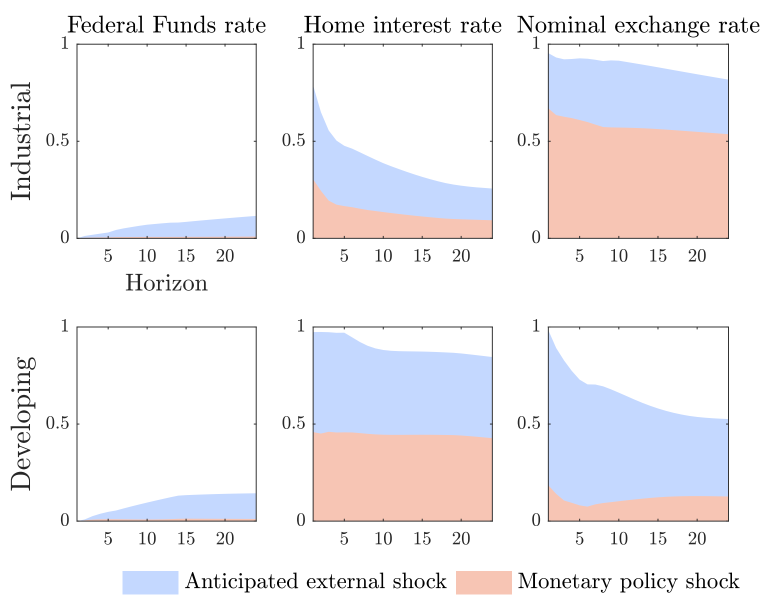


Figure A.2.1: Fraction of forecast error variance of each variable from identified shocks
Note: The variance decomposition is done with our baseline three-variable specification. The horizontal axes refer to forecast horizons, while the vertical axes denote the fraction of forecast error variance from each shock.

A.2.4 Empirical IRFs to an anticipated external shock (all countries)

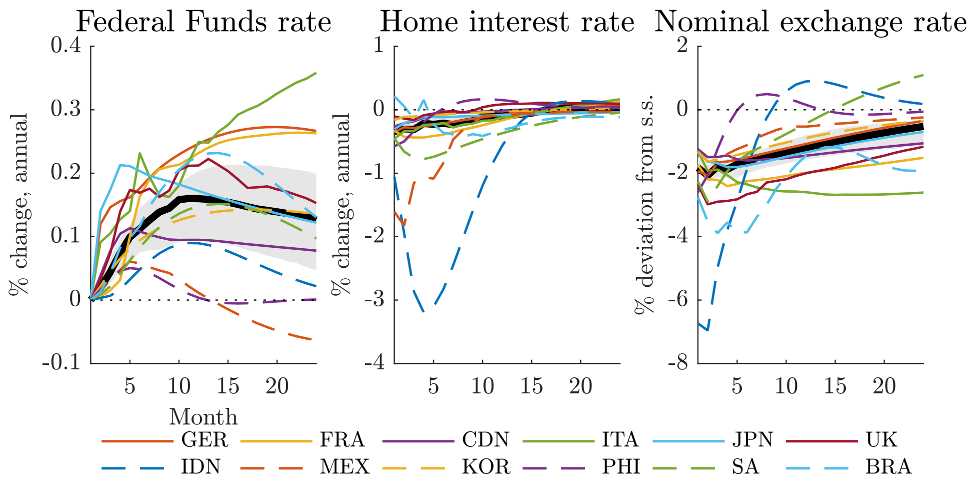


Figure A.2.2: Empirical IRFs to an anticipated external shock (all countries)
Note: Lines are the estimated IRFs to a one-standard-deviation anticipated external shock from the baseline three-variable VAR, for the preferred sample. Solid lines are IRFs for industrial countries; dashed lines are IRFs for developing and emerging countries. Thick black line is the median IRF for all countries and the shaded gray areas are the corresponding 90% confidence intervals from 1000 bias-corrected bootstrap replications of the reduced-form VAR.

A.2.5 Delayed overshooting

Using recursive identification strategies to identify the effect of monetary policy on exchange rates, Eichenbaum and Evans (1995) find a persistent appreciation of the domestic currency for periods up to 3 years following a monetary contraction. This empirical finding is known as the "delayed overshooting puzzle," and is also reported in Clarida and Gali (1994), and Scholl and Uhlig (2008), among others.[1] The delayed timing of the peak exchange rate response is interpreted as a puzzle because it is associated to deviations from UIP. In fact, after a temporary increase in the interest rate differential, the UIP condition implies

[1] Faust and Rogers (2003) and Cushman and Zha (1997) instead find no evidence of delayed overshooting.

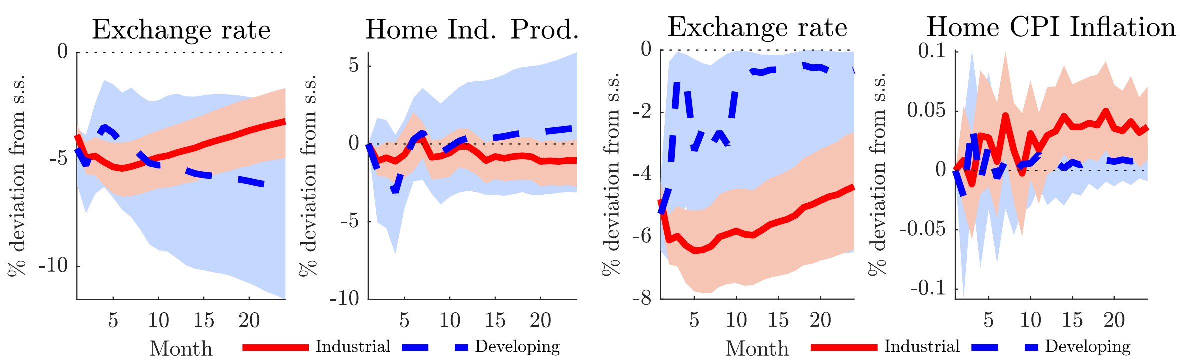
that the exchange rate should appreciate on impact and then depreciate until it reaches its long-run level (Dornbusch, 1976). Our findings about short-lived UIP deviations due to monetary policy shocks are consistent with the presence of a mild degree of delayed overshooting. Table A.2.3 reports the interquantile range of peak exchange rate responses across bootstraps. We find that most peak responses appear to occur within one year, with the exception of Japan, Canada, and South Africa. In general, the interquantile range is large, indicating a limited degree of delayed overshooting.

	Max Month		Max Month
Industrial countries		*Developing countries*	
Germany	3	Indonesia	0
	[1;69]		[0;1]
Canada	28	Brazil	14
	[10;94]		[1;53]
Italy	5	South Africa	29
	[3;34]		[10;45]
France	7	Korea	7
	[6;34]		[2;147]
Japan	116	Mexico	5
	[4;332]		[5;6]
United Kingdom	9	Philippines	0
	[6;14]		[0;5]

Table A.2.3: Test of delayed overshooting
Notes: We report the median value of the month of maximum response across bootstrap iterations. Interquantile range are reported in parentheses.

A.2.6 Multivariate VAR with domestic output and inflation

We extend our baseline VAR to account for the dynamics of domestic industrial production and CPI inflation, using two separate 4-variable VAR. Following Eichenbaum and Evans (1995), industrial production (in log difference) an CPI inflation are ordered second. Thus, innovations in output and inflation affect interest rates and exchange rates contemporaneously, while domestic monetary policy shocks influence these variable with a (one month) lag. In this setting, we identify four shocks: contemporaneous and anticipated external shocks, output/inflation shocks, and domestic monetary policy shocks. Accounting for the influence of output and inflation does not affect the response of the exchange rate to a domestic monetary policy innovation (under the alternative identification). Besides, a monetary contraction brings about a short-lived decline in output, in line with all monetary macro models. The inflation response to a monetary contractions appears insignificant in developing countries, while it generates the so-called price puzzle in industrial economies.

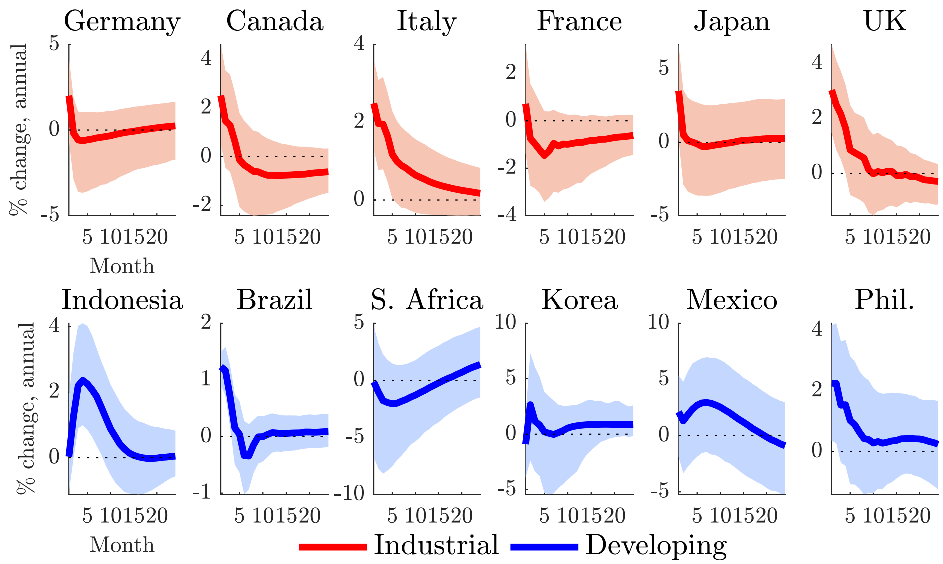


(a) Multivariate VAR with home output **(b)** Multivariate VAR with home inflation

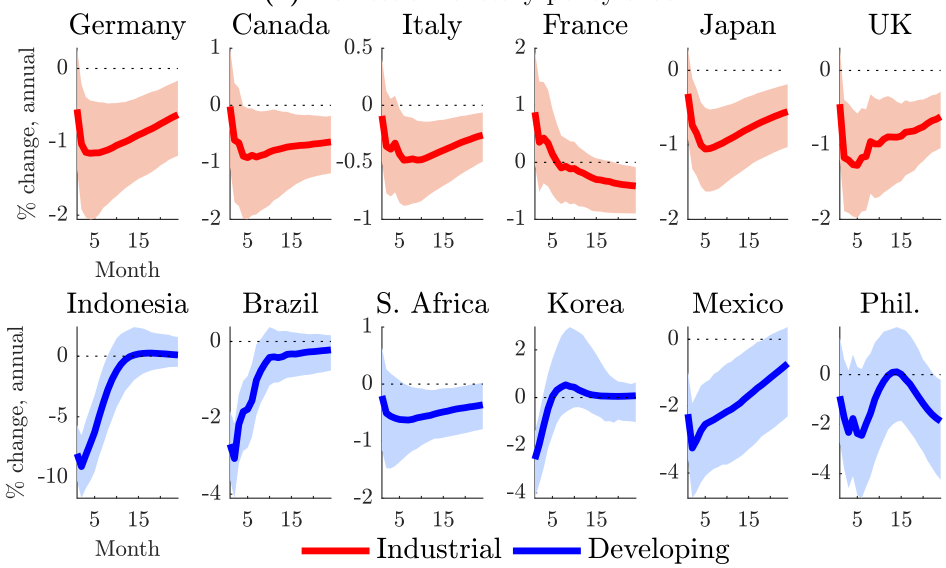
Figure A.2.3: Exchange rate, output and inflation responses to a 1% contractionary domestic monetary policy shock

Note: The figure shows the exchange rate response to a 1% contractionary domestic monetary policy shock (alternative identification), in a multivariate VAR that includes domestic industrial production growth (Panel A.2.3a) and domestic CPI inflation (Panel A.2.3b)

A.2.7 Excess returns, by country



(a) Domestic monetary policy shock



(b) Anticipated external shock

Figure A.2.4: Currency excess returns

Note: The figure shows the response of one-year ahead ex ante excess returns to a 1% domestic monetary policy shock (Panel A.2.4a) and a one-standard deviation anticipated external shock (Panel A.2.4b).

A.3 Model details

A.3.1 Traders's decision problem

This section shows that a CRRA utility has a mean-variance representation.

$$\max_{d_{t+1}} \mathrm{E}_t \left[\frac{(T^\star + \widetilde{R}_{t+1} d_{t+1})^{1-\omega_t^\star}}{1-\omega_t^\star} \right] = \mathrm{E}_t \left[\frac{\exp\left\{ (1-\omega_t^\star) \log(T^\star + \widetilde{R}_{t+1} d_{t+1}) \right\}}{1-\omega_t^\star} \right] \tag{A.1}$$

where $T^\star$ is such that $(T^\star + \widetilde{R}_{t+1} d_{t+1}) > 0$.

Take second order Taylor expansion around $\widetilde{R} = 0$:

$$\log(T^\star + \widetilde{R}_{t+1} d_{t+1}) \approx \log(T^\star) + \frac{d_{t+1}}{T^\star} \widetilde{R}_{t+1} - \frac{d_{t+1}^2}{2\,(T^\star)^2} \widetilde{R}_{t+1}^2 \tag{A.2}$$

$$\approx \log(T^\star) + \frac{d_{t+1}}{T^\star} \widetilde{R}_{t+1} - \frac{d_{t+1}^2}{2\,(T^\star)^2} \operatorname{Var}_t(\widetilde{R}_{t+1}) \tag{A.3}$$

where $\widetilde{R}_{t+1}^2$ is replaced by the conditional variance of $\widetilde{R}_{t+1}$.[2,3] Then Eq. (A.1) is approximated by:

$$\max_{d_{t+1}} \mathrm{E}_t \left[\frac{\exp\left\{ (1-\omega_t^\star) \left(\log(T^\star) + \frac{d_{t+1}}{T^\star} \widetilde{R}_{t+1} - \frac{d_{t+1}^2}{2(T^\star)^2} \operatorname{Var}_t(\widetilde{R}_{t+1}) \right) \right\}}{1-\omega_t^\star} \right] \tag{A.4}$$

[2] Note that $\mathrm{E}_t[\widetilde{R}_{t+1}]^2 \approx 0$.

[3] As the time interval shrinks, the higher order terms that are dropped from (A.1) become negligible relative to those that are included, and the deviation of $\widetilde{R}_{t+1}^2$ from $\operatorname{Var}_t(\widetilde{R}_{t+1})$ also become negligible. In particular in the limit of continuous time the approximation is exact and can be derived using Ito's Lemma.

$$\approx \max_{d_{t+1}} \exp\left\{(1-\omega_t^\star)\left(\log(T^\star) - \frac{d_{t+1}^2}{2\,(T^\star)^2}\operatorname{Var}_t(\widetilde{R}_{t+1})\right)\right\} \mathrm{E}_t\left[\exp\left\{(1-\omega_t^\star)\left(\frac{d_{t+1}}{T^\star}\widetilde{R}_{t+1}\right)\right\}\right]. \tag{A.5}$$

Assume normal distribution of $\widetilde{R}_{t+1}$, then

$$\approx \max_{d_{t+1}} \log(T^\star) - \frac{d_{t+1}^2}{2\,(T^\star)^2}\operatorname{Var}_t(\widetilde{R}_{t+1}) + (1-\omega_t^\star)\frac{d_{t+1}^2}{2\,(T^\star)^2}\operatorname{Var}_t(\widetilde{R}_{t+1}) + \frac{d_{t+1}}{T^\star}\mathrm{E}[\widetilde{R}_{t+1}] \tag{A.6}$$

$$\approx \max_{d_{t+1}} \mathrm{E}_t[\widetilde{R}_{t+1}]d_{t+1} - \frac{\omega_t^\star}{2T^\star}\operatorname{Var}_t(\widetilde{R}_{t+1})d_{t+1}^2 \tag{A.7}$$

In equilibrium, the individual trader's asset decisision reads

$$d_{t+1} = \frac{T^\star\,\mathrm{E}_t[\widetilde{R}_{t+1}]}{\omega_t^\star\operatorname{Var}_t(\widetilde{R}_{t+1})} \tag{A.8}$$

Without loss of generality, we set $T^\star = 1$. Then, aggregating over the m_t measure of traders, the overall demand for domestic bonds from traders is

$$\widetilde{D}_{t+1} = \frac{m_t}{\omega_t^\star}\frac{\mathrm{E}_t\,\widetilde{R}_{t+1}}{\operatorname{Var}_t(\widetilde{R}_{t+1})} \tag{A.9}$$

which is Eq. (1.15) in the text.

A.3.2 Model equilibrium equations

Besides each country's Phillips Curve, the model's equilibrium equations in levels are given by:

$$\beta^\star \operatorname{E}_t \left[\left(C^\star_{t+1} \right)^{-\omega^\star \exp(\omega^\star_{t+1})} \frac{R^\star_t}{\Pi^\star_{t+1}} \right] = (C^\star_t)^{-\omega^\star \exp(\omega^\star_t)}$$

$$\frac{R^\star_t}{R^\star} = \left(\frac{R^\star_{t-1}}{R^\star} \right)^{\rho_R} \left(\frac{\Pi^\star_t}{\Pi^\star} \right)^{(1-\rho_R)\phi} \exp\left(\varepsilon_{r^\star,t} \right)$$

$$\beta \operatorname{E}_t \left[(C_{t+1})^{-\omega} \frac{R_t}{\Pi_{t+1}} \right] = (C_t)^{-\omega}$$

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left(\frac{\Pi_t}{\Pi} \right)^{(1-\rho_R)\phi} \exp\left(\varepsilon_{r,t} \right)$$

$$\Pi_t = (\Pi_{H,t})^{1-\lambda} \left(\frac{S_t}{S_{t-1}} \Pi^\star_t \right)^{\lambda}$$

$$Y_t = Q_t^{\frac{\theta\lambda}{1-\lambda}} \left\{ (1-\lambda) C_t + \lambda Q_t^{\theta} C^\star_t \right\}$$

$$\frac{{}^{B_{t+1}}\!/\!{}_{P_{H,t} Y_t}}{R_t} - {}^{B_t}\!/\!{}_{P_{H,t-1} Y_{t-1}} \frac{1}{\Pi_{H,t} {}^{Y_t}\!/\!{}_{Y_{t-1}}} = 1 - Q_t^{-\frac{\lambda}{1-\lambda}} \frac{C_t}{Y_t}$$

$$S_t = Q_t \frac{P_t}{P_t^\star}$$

$$-{}^{B_{t+1}}\!/_{P_{H,t}Y_t} = \frac{\mu\, \mathrm{E}_t\left(R_t - R_t^\star \frac{S_{t+1}}{S_t}\right)}{\mathrm{Var}_t\left(R_t - R_t^\star \frac{S_{t+1}}{S_t}\right)}$$

A.3.3 Model solution

We can represent the model outlined in Appendix A.3.2 as the following system of equations:

$$\mathrm{E}_t\left[f(X_{t+1})\right] = 0$$

where X_{t+1} contains all the variables in the model (including variables dated at time t and $t-1$) and f has as many rows as endogenous variables in the model. The risky steady state (Coeurdacier, Rey and Winant, 2011) is obtained by taking a second-order approximation of f around $\mathrm{E}_t\, X_{t+1}$:

$$\Phi\left(\mathrm{E}_t\, X_{t+1}\right) = f\left(\mathrm{E}_t\, X_{t+1}\right) + \mathrm{E}_t\left[f''\left[X_{t+1} - \mathrm{E}_t\, X_{t+1}\right]^2\right]$$

where f'' is also evaluated at $\mathrm{E}_t\, X_{t+1}$. The risky steady state, $\mathtt{X}$, is then characterized by $\Phi\left(\mathtt{X}\right) = 0$, and the second moments $\mathrm{E}_t\left[f''\left[X_{t+1} - \mathrm{E}_t\, X_{t+1}\right]^2\right]$ are generated by the linear dynamics around $\mathtt{X}$.

The model's solution thus consists in a log-linear approximation around a risky steady state that is consistent with the second moments generated by the log-linear dynamics around it. This is achieved through an iterative algorithm, along the lines of Coeurdacier, Rey and Winant (2011).

Appendix B

Should Central Banks Target Investment Prices?

B.1 Optimal price setting

Denote by $1-\xi_j$ the probability that a firm in sector j can re-optimize price setting. A firm that can renew its price contract chooses $P_{j,t}(f)$ to maximize its expected discounted dividend flows given by:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \xi_j^s D_{t,t+s} \left[(1+\tau_j) P_{j,t}(f) Y_{j,t+s}^d(f) - V_{j,t+s}(f) \right]$$

where τ_j denotes a subsidy to sector-j output, $D_{t,t+s}$ is the period-t present value of a dollar in a future state in period $t+s$, and $V_{j,t+s}(f)$ is the total cost function; in maximizing its profits, each firm takes as given its demand schedule (2.1). The resulting optimal pricing rule is:

$$P_{j,t}(f) = \frac{\mu_j}{1+\tau_j} \frac{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_j^s D_{t,t+s} v_{j,t+s} \left(\frac{P_{j,t+s}}{\Pi_j^s}\right)^{\frac{1+\theta_j}{\theta_j}} Y_{j,t+s}}{\mathbb{E}_t \sum_{s=0}^{\infty} \xi_j^s D_{t,t+s} \left(\frac{P_{j,t+s}}{\Pi_j^s}\right)^{\frac{1}{\theta_j}} Y_{j,t+s}} \tag{B.1}$$

where $v_{j,t}$ denotes the real marginal cost function (in units of the respective sectoral price index) given by (2.2).

The steady state of (B.1), with constant *real* marginal costs, reads

$$\frac{P_{j,t}(f)}{P_{j,t}} = \frac{\mu_j}{1+\tau_j} v_j \tag{B.2}$$

It is important to note that, under full indexation to trend inflation, the steady state coincides with the flexible price steady state: each firm sets its price as a constant markup over marginal costs. This assumption guarantees that the steady state is not distorted by trend inflation. In the steady state, however, the markup is completely offset by the subsidy τ_j. This assumption guarantees that the steady state of the model is not distorted by imperfect competition.

The log-linearized counterpart of (B.1) – the log-linearized optimal price setting rule equation – is:

$$p_{j,t}^* - p_{j,t} = (1-\xi_j\tilde{\beta})\mathbb{E}_t \sum_{s=0}^{\infty} (\xi_j\tilde{\beta})^s \left[\pi_{j,t|t+s} + mc_{j,t+s}\right] \tag{B.3}$$

where mc_j denotes log-linearized sector-j *sector-j-real* marginal costs. One can show that the (sectoral) price level evolves as:

$$P_{j,t} = \left[\xi_j (\Pi_j P_{j,t-1})^{-\frac{1}{\theta_j}} + (1-\xi_j)(P^*_{j,t})^{-\frac{1}{\theta_j}} \right]^{-\theta_j} \tag{B.4}$$

where $1-\xi_j$ denotes the probability of adjusting the price in a given period, and θ_j represent the mark-up rate in sector j. One can rewrite (B.5) as:

$$1 = \xi_j \Pi_j^{-\frac{1}{\theta_j}} \Pi_{j,t}^{\frac{1}{\theta_j}} + (1-\xi_j) \left(\frac{P^*_{j,t}}{P_{j,t}} \right)^{-\frac{1}{\theta_j}} \tag{B.5}$$

Its log-linearized counterpart – the log-linearized general price level equation – is:

$$p^*_{j,t} - p_{j,t} = \frac{\xi_j}{1-\xi_j} \pi_{j,t} \tag{B.6}$$

Note that both (B.3) and (B.6) are independent from trend inflation *and* exactly coincide with their counterparts derived under zero steady-state inflation. As a result, putting them together, one obtains the usual (sectoral) New Keynesian Phillips curve(s).

B.2 Stationary equilibrium, the deterministic steady state, and log-linear equilibrium equations

To induce stationarity we transform variables as follows:[1]

$$\hat{C}_t = \hat{Y}_{c,t} = \frac{Y_{c,t}}{\Gamma_{c,t}^{1-\alpha}\Gamma_{i,t}^{\alpha}} \qquad \hat{I}_t = \hat{Y}_{i,t} = \frac{Y_{i,t}}{\Gamma_{i,t}} \qquad \hat{K}_{j,t+1} = \frac{K_{j,t+1}}{\Gamma_{i,t}} \qquad \hat{w}_{j,t} = \frac{W_{j,t}}{P_{c,t}\Gamma_{c,t}^{1-\alpha}\Gamma_{i,t}^{\alpha}}$$

$$\hat{q}_{i,t} = \frac{q_{i,t}}{\Gamma_{c,t}^{1-\alpha}\Gamma_{i,t}^{\alpha-1}} = \frac{P_{i,t}}{P_{c,t}}\left(\frac{\Gamma_{i,t}}{\Gamma_{c,t}}\right)^{1-\alpha} \qquad \frac{\hat{mc}_{i,t}}{q_{i,t}} = \frac{MC_{i,t}}{P_{i,t}} = \frac{MC_{i,t}}{P_{c,t}q_{i,t}} \qquad \hat{mc}_{c,t} = \frac{MC_{c,t}}{P_{c,t}} \qquad \hat{q}^k_{j,t} = q^k_{j,t}\left(\frac{\Gamma_{i,t}}{\Gamma_{c,t}}\right)^{1-\alpha}$$

$$\hat{r}^k_{j,t} = r^k_{j,t}\left(\frac{\Gamma_{i,t}}{\Gamma_{c,t}}\right)^{1-\alpha} \qquad \hat{Y}_t = \frac{Y_t}{\Gamma_{c,t}^{1-\alpha}\Gamma_{i,t}^{\alpha}}$$

The household's FOCs (2.8)-(2.11) are rendered stationary as follows:

$$\upsilon_j N_{j,t}(h)^{\eta} = \frac{\hat{w}_{j,t}}{\hat{C}_t^{\sigma}}$$

$$1 = \beta(\gamma_c^{1-\alpha}\gamma_i^{\alpha})^{-\sigma}\mathbb{E}_t\left[\frac{R_t^n}{\Pi_{c,t+1}}\frac{\hat{C}_{t+1}^{-\sigma}}{\hat{C}_t^{-\sigma}}\right]$$

$$\hat{q}_{i,t} = \hat{q}^k_{j,t}\left[\Psi'\left(\frac{\hat{I}_{j,t}\gamma_i}{\hat{K}_{j,t}}\right)\right]$$

$$\hat{q}^k_{j,t} = \tilde{\beta}\gamma_i^{-1}\mathbb{E}_t\left(\frac{\hat{C}_{t+1}}{\hat{C}_t}\right)^{-\sigma}\left\{\hat{q}^k_{j,t+1}\left[1-\delta+\Psi\left(\frac{\hat{I}_{j,t+1}\gamma_i}{\hat{K}_{j,t+1}}\right)-\Psi'\left(\frac{\hat{I}_{j,t+1}\gamma_i}{\hat{K}_{j,t+1}}\right)\left(\frac{\hat{I}_{j,t+1}\gamma_i}{\hat{K}_{j,t+1}}\right)\right]+\hat{r}^k_{j,t+1}\right\} \quad \text{(B.7)}$$

where γ_j denotes the growth rate of sector-j technology.

[1] Hatted variables are stationary

Sector-j production function reads:

$$\hat{Y}_{j,t} = Z_{j,t}\left(\gamma_i^{-1}\hat{K}_{j,t}\right)^{\alpha}(L_{j,t})^{1-\alpha}$$

Real marginal costs in the consumption sector:

$$\frac{MC_{c,t}}{P_{c,t}} = \frac{\tilde{\alpha}}{Z_{c,t}}(\hat{r}^k_{c,t})^{\alpha}(\hat{w}_{c,t})^{1-\alpha}$$

Investment-real marginal costs in the investment sector:

$$\frac{MC_{i,t}}{P_{i,t}} = \frac{\tilde{\alpha}}{Z_{i,t}}(\hat{r}^k_{i,t})^{\alpha}(\hat{w}_{i,t})^{1-\alpha}\frac{1}{\hat{q}_{i,t}}$$

Factor demands are given by:

$$\frac{\hat{w}_{j,t}}{\hat{r}^k_{j,t}} = \frac{1-\alpha}{\alpha}\frac{\gamma_i^{-1}\hat{K}_{j,t}}{L_{j,t}}$$

Capital laws of motion are denoted by:

$$\hat{K}_{j,t+1} = \frac{(1-\delta)}{\gamma_i}\hat{K}_{j,t} + \left(\Psi\left(\frac{\hat{I}_{j,t}\gamma_i}{\hat{K}_{j,t}}\right)\right)\frac{\hat{K}_{j,t}}{\gamma_i}$$

The Euler equation in steady state imply:

$$R^n = \beta^{-1}(\gamma_c^{1-\alpha}\gamma_i^{\alpha})^{\sigma}\Pi_c$$

where Π_c denotes the steady-state PCE inflation rate. This has to satisfy:

$$\hat{q}_{i,t} = \frac{P_{i,t}}{P_{c,t}} \left(\frac{\Gamma_{i,t}}{\Gamma_{c,t}} \right)^{1-\alpha} \tag{B.8}$$

Divide both sides of (B.8) by its previous period counterpart:

$$1 = \frac{\Pi_{i,t}}{\Pi_{c,t}} \left(\frac{\gamma_i}{\gamma_c} \right)^{1-\alpha} \tag{B.9}$$

which states that the relative price of investment decline at a rate that is determined by the growth rate differential of sectoral technologies. Then, for given sectoral technology growth rates, we can calibrate one sectoral steady-state inflation rate, and the other would be uniquely determined, by (B.9).

The capital laws of motion in steady state imply:

$$\frac{\hat{I}_j}{\hat{K}_j} = 1 - \frac{1-\delta}{\gamma_i} \tag{B.10}$$

which is the investment-capital ratio in sector j. The log-linearized equilibrium conditions are reported in Table B.2.1.

Production functions	$y_{j,t} = z_{j,t} + \alpha k_{j,t} + (1-\alpha)h_{j,t}$
C-sector real marginal costs	$v_{c,t} = \alpha r^k_{c,t} + (1-\alpha)w_{c,t} - z_{c,t}$
I-sector real marginal costs	$v_{i,t} = \alpha r^k_{i,t} + (1-\alpha)w_{i,t} - z_{i,t} - q_{i,t}$
Factors demands	$w_{j,t} = r^k_{j,t} + k_{j,t} - h_{j,t}$
Labor-supply schedules	$h_{j,t} = (1/\eta)(w_{j,t} - \sigma c_t)$
Consumption Euler equation	$\mathbb{E}_t \Delta c_{t+1} = (1/\sigma)(r^n_t - \mathbb{E}_t \pi_{c,t+1})$
Shadow value of capital	$q^k_{j,t} = q_{i,t} + \psi\tilde{\delta}\gamma_i(i_{j,t} - k_{j,t})$
Investment demands	$q^k_{j,t} = -\sigma \mathbb{E}_t \Delta c_{t+1} + \tilde{\beta}(1-\tilde{\delta})\mathbb{E}_t q^k_{j,t+1} +$ $\left(1-\tilde{\beta}(1-\tilde{\delta})\right)\mathbb{E}_t r^k_{j,t+1} +$ $\tilde{\beta}\tilde{\delta}\psi\tilde{\delta}\gamma_i \mathbb{E}_t\left(i_{j,t+1} - k_{j,t+1}\right)$
Capital laws of motion	$k_{j,t+1} = (1-\tilde{\delta})k_{j,t} + \tilde{\delta} i_{j,t}$
Labor market clearing	$h_t = \phi h_{c,t} + (1-\phi)h_{i,t}$
Investment market clearing	$i_t = \phi i_{c,t} + (1-\phi)i_{i,t}$
Agg. resource constraint	$y_t = \phi c_t + (1-\phi)i_t$
	for $j = \{c, i\}$

Table B.2.1: Log-linearized equilibrium conditions

Note: In addition, $c_t = y_{c,t}$ and $i_t = y_{i,t}$ also hold in equilibrium, as well as the definition of relative price, (2.15), and sectoral Phillips curves, (2.13) and (2.14). I-sector real marginal costs are expressed in investment units. Also, $\tilde{\delta} = 1 - \frac{1-\delta}{\gamma_i}$

B.3 The relationship between marginal cost gaps and output gaps

By using the log-linearized c-sector marginal costs, capital demand, labor supply, production function and resource constraint (see Table B.2.1) we have:

$$v_{c,t} = \left[\frac{(1+\eta)}{1-\alpha} - (1-\sigma)\right] c_t - \alpha\frac{1+\eta}{1-\alpha}k_{c,t} - \frac{1+\eta}{1-\alpha}z_{c,t}$$

The last equation represents the real marginal costs in the consumption sector under sticky prices. The following equation defines the real marginal costs when prices are flexible, under the Woodford's definition of natural rates:[2]

$$v^*_{c,t} = \left[\frac{(1+\eta)}{1-\alpha} - (1-\sigma)\right] c^*_t - \alpha\frac{1+\eta}{1-\alpha}k_{c,t} - \frac{1+\eta}{1-\alpha}z_{c,t}$$

Recall that, in every time period, the variation in real marginal costs under flexible prices is nil. That is, prices are set as a constant markup over nominal marginal costs. Thus the marginal cost equals the marginal cost gap and is given by:

$$v_{c,t} - v^*_{c,t} = \left[\frac{(1+\eta)}{1-\alpha} - (1-\sigma)\right](c_t - c^*_t)$$

[2] As explained in Section 2.4, the Woodford's definition of natural rate implies that period-t capital stocks in the Pareto-optimal equilibrium coincide with period-t capital stocks in the sticky price equilibrium. Note that this is not true for $t+i$ if $i \neq 0$

Similarly one can show that, under sticky prices, the real marginal costs in the investment sector, in units of investment goods, are:

$$v_{i,t} = \left[\frac{1+\eta}{1-\alpha} - 1\right] i_t - \alpha\frac{1+\eta}{1-\alpha}k_i + \sigma c_t - \frac{1+\eta}{1-\alpha}z_{i,t} - q_{i,t}$$

Under flexible prices, these correspond to

$$v^*_{i,t} = \left[\frac{1+\eta}{1-\alpha} - 1\right] i^*_t - \alpha\frac{1+\eta}{1-\alpha}k_i + \sigma c^*_t - \frac{1+\eta}{1-\alpha}z_{i,t} - q^*_{i,t}$$

The investment marginal costs gap is therefore:

$$v_{i,t} - v^*_{i,t} = \left[\frac{1+\eta}{1-\alpha} - 1\right](i_t - i^*_t) + \sigma\left(c_t - c^*_t\right) - \left(q_{i,t} - q^*_{i,t}\right)$$

B.4 Pareto optimum

Here we outline some flexible-price equilibrium relationships that will prove useful in deriving the second-order approximation to the social welfare function. By equating the marginal rate of substitution to the marginal product of labor in the consumption sector, under flexible prices, we obtain:

$$\sigma c^*_t + \eta h^*_{c,t} = c^*_t - h^*_{c,t}$$

Use the production function to substitute out for consumption-sector labor:

$$h^*_{c,t} = \frac{1}{1-\alpha} c^*_t - \frac{\alpha}{1-\alpha} k_{c,t} - \frac{1}{1-\alpha} z_{c,t}$$

$$\frac{1+\eta}{1-\alpha} \left(\alpha k_{c,t} + z_{c,t}\right) = \left[\frac{1+\eta}{1-\alpha} - (1-\sigma)\right] c^*_t \tag{B.11}$$

Note that, under Woodford's definition of natural rate, $k^*_{c,t} = k_{c,t}$ at the beginning of each time period.

The production function for investment goods, together with the market-clearing condition in the investment sector, imply:

$$z_{i,t} + \alpha k_{i,t} = i^*_t + (1-\alpha) h^*_{i,t} \tag{B.12}$$

B.5 A second-order approximation to the welfare function

The approach adopted in this section largely follows Erceg, Henderson and Levin (2000) and Edge (2003).

To provide a normative assessment of alternative monetary policy choices, we measure social welfare as the unconditional expectation of average household lifetime utility:

$$\mathbb{E}_t \int_0^1 \left[\sum_{s=0}^{\infty} \tilde{\beta}^s \mathbb{W}_{t+s}(h)\right] dh$$

where $\tilde{\beta} = \beta(\gamma_c^{1-\alpha}\gamma_i^{\alpha})^{1-\sigma}$, and the term in large brackets is the discounted lifetime utility function of household h presented in the paper (Equations (2.5) and (2.6) after appropriate transformations). In this appendix, we follow the seminal analysis of Rotemberg and Woodford (1997) in deriving the second-order approximation to each component of the social welfare function and computing its deviation from the welfare of the Pareto-optimal equilibrium under flexible consumption and investment prices. We adopt Woodford's definition of natural rate of output: as explained in Section 2.4, when we enter period $t+1$ it is the capital stock that is *actually* present that determines how output in $t+1$ is defined. We will be more specific on the implications of this assumption below. The approach we take can be described as follows: we derive the second order approximation for the within-period welfare function in the sticky price model; we subtract its flexible-price counterpart; we take sum over t from 0 to ∞ and take the unconditional expectation.

It is useful to decompose household h's period utility function $\mathbb{W}_t(h)$ as follows:

$$\mathbb{W}_t = \mathbb{U}(\hat{C}_t) - \mathbb{V}^c(N_{c,t}(h)) - \mathbb{V}^i(N_{i,t}(h))$$

$$\mathbb{U}(\hat{C}_t) = \frac{\hat{C}_t^{1-\sigma}}{1-\sigma}$$

$$\mathbb{V}^c(N_{c,t}(h)) = \upsilon_c \frac{N_{c,t}(h)^{1+\eta}}{1+\eta}$$

$$\mathbb{V}^c(N_{i,t}(h)) = \upsilon_i \frac{N_{i,t}(h)^{1+\eta}}{1+\eta}$$

We use two approximations repeatedly. If A is a generic variable, the relationship between its arithmetic and logarithmic percentage change is

$$\frac{A-\bar{A}}{\bar{A}}=\frac{dA}{\bar{A}}\simeq a+\frac{1}{2}a^2,\ a\equiv \ln A-\ln\bar{A} \tag{B.13}$$

If $A=\left[\int_0^1 A(j)^{\phi}dj\right]^{\frac{1}{\phi}}$, the logarithmic approximation of A is

$$a\simeq E_j a(j)+\frac{1}{2}\phi\left(E_j a(j)^2-(E_j a(j))^2\right)=E_j a(j)+\frac{1}{2}\phi var_j a(j) \tag{B.14}$$

We first consider the subutility functions that involve consumption terms, that is $\mathbb{U}(\hat{C}_t)$ and $\mathbb{V}^c(N_{c,t}(h))$; first, we approximate $\mathbb{U}(\hat{C}_t)$:[3]

$$\mathbb{U}(\hat{C})\simeq\mathbb{U}+\mathbb{U}_{\hat{C}}\hat{C}\frac{d\hat{C}}{\hat{C}}+\frac{1}{2}\left(\mathbb{U}_{\hat{C}\hat{C}}\hat{C}^2\left(\frac{d\hat{C}}{\hat{C}}\right)^2\right)$$

Making use of Equation (B.13) we have:

$$\mathbb{U}(\hat{C})\simeq\mathbb{U}+\mathbb{U}_{\hat{C}}\hat{C}\left(c+\frac{1}{2}c^2\right)+\frac{1}{2}\mathbb{U}_{\hat{C}\hat{C}}\hat{C}^2c^2 \tag{B.15}$$

Next we approximate $E_h\mathbb{V}^c(N_{c,t})$:

$$E_h\mathbb{V}^c(N_{c,t}(h))\simeq\mathbb{V}^c+E_h\mathbb{V}^c_{N_c}N_c\frac{dN_c(h)}{N_c}+\frac{1}{2}\left(E_h\mathbb{V}^c_{N_cN_c}N_c^2\left(\frac{dN_c(h)}{\bar{N}_c}\right)^2\right)$$

[3] In this section we suppress the time subscript t for ease of notation.

Again, by (B.13) we can write:

$$E_h \mathbb{V}^c(N_{c,t}(h)) \simeq \mathbb{V}^c + \mathbb{V}^c_{N_c} N_c \left(E_h n_c(h) + \frac{1}{2} E_h n_c(h)^2 \right) + \frac{1}{2} \left(\mathbb{V}^c_{N_c N_c} N_c^2 E_h n_c(h)^2 \right) \quad \text{(B.16)}$$

The aggregate supply of labor in the consumption sector is $L_c = \nu_c \int_0^1 N_c(h)dh$. Therefore,

$$l_c = \ln \nu_c + \ln \int_0^1 N_{c,t}(h)dh - \ln \bar{L}_c \simeq E_h n(h) + \frac{1}{2} var_h n_c(h) \quad \text{(B.17)}$$

where the constant terms are dropped in the last equation. The aggregate demand for labor by firms (in the consumption sector) is $L_c = \int_0^1 L_c(f)df = E_f L_c(f)$. Thus,

$$l_c = \ln E_f L_c(f) - \bar{L}_c \simeq E_f l_c(f) + \frac{1}{2} var_f l_c(f) \quad \text{(B.18)}$$

All firms in the consumption sector choose identical capital labor ratios $\left(\frac{\hat{K}_c(f)}{L_c(f)}\right)$ equal to the aggregate sectoral ratio $\frac{\hat{K}_c}{L_c}$ because they face the same factor prices, so

$$\hat{Y}_c(f) = Z_c \left(\frac{\hat{K}_c(f)}{L_c(f)} \right)^{\alpha} L_c(f) = Z_c \left(\frac{\hat{K}_c}{L_c} \right)^{\alpha} L_c(f)$$

The last equation implies:

$$y_c(f) = z_c + \alpha k_c - \alpha l_c + l_c(f)$$

which also implies:

$$E_f y_c(f) = z_c + \alpha k_c - \alpha l_c + E_f l_c(f) \tag{B.19}$$

and:

$$var_f y_c(f) = var_f l_c(f) \tag{B.20}$$

Using (B.19) and (B.20) into (B.18), and eliminating $E_f y_c(f)$ using (B.14) yields:

$$l_c \simeq \frac{1}{1-\alpha}(y_c - z_c) - \left(\frac{\alpha}{1-\alpha}\right) k_c + \frac{1}{2}\left(\frac{1}{1-\alpha}\right)\left(\frac{\theta_c}{1+\theta_c}\right) var_f y_c(f) \tag{B.21}$$

Solving (B.17) for $E_h n_c(h)$, eliminating l using (B.21), and noticing that, in absence of nominal wage rigidities, there is no variation in hours worked across *households* (i.e. $var_h n_c(h) = 0$), we have:

$$E_h n_c(h) \simeq \frac{1}{1-\alpha}(y_c - z_c - \alpha k_c) + \frac{1}{2}\left(\frac{1}{1-\alpha}\right)\left(\frac{\theta_c}{1+\theta_c}\right) var_f y_c(f) \tag{B.22}$$

Also note that $E_h n_c(h)^2 = var_h n_c(h) + [E_h n_c(h)]^2$. Thus, taking squares of both sides of (B.22):

$$E_h n_c(h)^2 \simeq \left(\frac{1}{1-\alpha}\right)^2 (y_c - z_c - \alpha k_c)^2 \tag{B.23}$$

Replacing (B.22) and (B.23) in (B.16) yields:

$$E_h \mathbb{V}^c(N_{c,t}(h)) \quad \simeq \quad \mathbb{V}^c + \mathbb{V}^c_{N_c} N_c \left[\frac{1}{1-\alpha}(y_c - z_c) - \left(\frac{\alpha}{1-\alpha}\right) k_c\right]$$

$$+\frac{1}{2}\mathbb{V}^c_{N_c}N_c\left(\frac{1}{1-\alpha}\right)\left(\frac{\theta_c}{1+\theta_c}\right)var_f y_c(f)$$
$$+\frac{1}{2}\left[\mathbb{V}^c_{N_c}N_c+\mathbb{V}^c_{N_cN_c}N_c^2\right]\left[\left(\frac{1}{1-\alpha}\right)^2(y_c-z_c-\alpha k_c)^2\right] \tag{B.24}$$

Also, *in steady state*, if we equate the marginal rate of substitution to the marginal product of labor in sector j, we have:[4]

$$\frac{\mathbb{V}^j_{N_j}}{\mathbb{U}_{\hat{C}}}=(1-\alpha)\frac{\hat{Y}_j}{N_j}$$

When $j=c$:

$$\frac{\mathbb{V}^c_{N_c}N_c}{(1-\alpha)}=\mathbb{U}_{\hat{C}}\hat{C} \tag{B.25}$$

When $j=i$:

$$\frac{\mathbb{V}^i_{N_i}N_i}{(1-\alpha)}=\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C} \tag{B.26}$$

Also, since $\mathbb{V}^c(N_{c,t}(h))=\upsilon_c\frac{N_{c,t}(h)^{1+\eta}}{1+\eta}$, we have that $\mathbb{V}^c_{N_c}N_c=\upsilon_c {N_c}^{1+\eta}$ and $\mathbb{V}^c_{N_cN_c}N_c^2=\eta\mathbb{V}^c_{N_c}N_c$. Moreover, given that $\mathbb{U}(\hat{C}_t)=\frac{\hat{C}_t^{1-\sigma}}{1-\sigma}$, it also holds that $\mathbb{U}_{\hat{C}}\hat{C}=\hat{C}^{1-\sigma}$ and $\mathbb{U}_{\hat{C}\hat{C}}\hat{C}^2=-\sigma\mathbb{U}_{\hat{C}}\hat{C}$. Use (B.25) together with the above relationships into (B.24) and sum the resulting equation to (B.15). This leads to:[5]

$$\mathbb{U}(\hat{C})-E_h\mathbb{V}^c(N_{c,t}(h))\simeq\mathbb{U}-\mathbb{V}^c+\mathbb{U}_{\hat{C}}\hat{C}\,(z_c+\alpha k_c)+\frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\,(1-\sigma)\,c^2$$
$$-\frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_c}{1+\theta_c}\right)var_f y_c(f)$$
$$-\frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)(c-z_c-\alpha k_c)^2\right] \tag{B.27}$$

[4] Note that the markup and and subsidy exactly cancel each other out in steady state, in both sectors

[5] Here we also used the fact that $y_c=c$ which holds in our model since we abstract from government purchases.

Let's now consider the component of the utility function related to investment. This coincides with the term that describes disutility from labor allocated in the investment sector. The derivation is similar to the one concerning $\mathbb{V}^c$. Thus:

$$\begin{aligned} E_h\mathbb{V}^i(N_i(h)) \simeq \mathbb{V}^i + \mathbb{V}^i_{N_i}N_i\left[\frac{1}{1-\alpha}(y_i - z_i) - \left(\frac{\alpha}{1-\alpha}\right)k_i\right] \\ + \frac{1}{2}\mathbb{V}^i_{N_i}N_i\left(\frac{1}{1-\alpha}\right)\left(\frac{\theta_i}{1+\theta_i}\right)var_f y_i(f) \\ + \frac{1}{2}\left[\mathbb{V}^i_{N_i}N_i + \mathbb{V}^i_{N_iN_i}N_i^2\right]\left[\left(\frac{1}{1-\alpha}\right)^2(y_i - z_i - \alpha k_i)^2\right] \end{aligned} \tag{B.28}$$

By (B.26) and $i = y_i$ we can rewrite (B.28) as:

$$\begin{aligned} E_h\mathbb{V}^i(N_i(h)) \simeq \mathbb{V}^i + \frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\left[i - z_i - \alpha k_i\right] + \frac{1}{2}\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_i}{1+\theta_i}\right)var_f y_i(f) \\ + \frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)(i - z_i - \alpha k_i)^2\right] \end{aligned} \tag{B.29}$$

To obtain the within-period welfare function under sticky prices, sum Eqs. (B.27) and (B.29):

$$\begin{aligned} \mathbb{W}_t \simeq \mathbb{U} - \mathbb{V}^c + \mathbb{U}_{\hat{C}}\hat{C}\alpha k_c + \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\;(1-\sigma)c^2 - \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_c}{1+\theta_c}\right)var_f y_c(f) \\ - \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)(c - z_c - \alpha k_c)^2\right] - \mathbb{V}^i - \frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\left[i - \alpha k_i\right] \\ - \frac{1}{2}\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_i}{1+\theta_i}\right)var_f y_i(f) - \frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)(i - z_i - \alpha k_i)^2\right] \end{aligned} \tag{B.30}$$

Consider now the *first-order* terms in the first line of the above equation:

$$\alpha k_{c,t} - \frac{1-\phi}{\phi}\left[i_t - \alpha k_{i.t}\right]$$

Note that $i_t = \phi i_{c,t} + (1-\phi) i_{i,t}$ and for $j = \{c, i\}$: $k_{j,t+1} = (1-\tilde{\delta})k_{j,t} + \tilde{\delta} i_{j,t}$. Thus:

$$\alpha k_{c,t} - \frac{(1-\phi)}{\tilde{\delta}} k_{c,t+1} + \frac{(1-\phi)(1-\tilde{\delta})}{\tilde{\delta}} k_{c,t} - \frac{(1-\phi)^2}{\phi\tilde{\delta}} k_{i,t+1} + \frac{(1-\phi)^2(1-\tilde{\delta})}{\phi\tilde{\delta}} k_{i,t} + \frac{(1-\phi)}{\phi} \alpha k_{i,t} \tag{B.31}$$

The net rental rate of capital in steady state (in units of investment goods) is:

$$r_j^k = \frac{\gamma_i}{\tilde{\beta}} - (1-\delta) \tag{B.32}$$

By the law of motion in the investment sector, evaluated in steady state: $\frac{I_i}{K_i} = \frac{\hat{I}_i \gamma_i}{\hat{K}_i} = \gamma_i - (1-\delta)$. Also, by the investment-sector steady-state capital demand:

$$r_i^k = \alpha \frac{Y_i}{K_i} = \alpha \frac{[\gamma_i - (1-\delta)]\, I}{I_i} = \alpha \frac{[\gamma_i - (1-\delta)]}{1-\phi} \tag{B.33}$$

By equating (B.32) and (B.33):

$$\frac{1-\phi}{\tilde{\delta}} = \frac{\alpha\tilde{\beta}}{1-\tilde{\beta}(1-\tilde{\delta})} \tag{B.34}$$

Use (B.34) in (B.31):

$$\begin{aligned}
&\alpha k_{c,t} - \frac{\alpha\tilde{\beta}}{1-\tilde{\beta}(1-\tilde{\delta})} k_{c,t+1} + \frac{\alpha\tilde{\beta}}{1-\tilde{\beta}(1-\tilde{\delta})}(1-\tilde{\delta}) k_{c,t} \\
&+ \frac{(1-\phi)}{\phi}\left[- \frac{\alpha\tilde{\beta}}{1-\tilde{\beta}(1-\tilde{\delta})} k_{i,t+1} + \frac{\alpha\tilde{\beta}}{1-\tilde{\beta}(1-\tilde{\delta})}(1-\tilde{\delta}) k_{i,t} + \alpha k_{i,t} \right] \\
&+ \left[\frac{\alpha}{1-\tilde{\beta}(1-\tilde{\delta})} \left(k_{c,t} - \tilde{\beta} k_{c,t+1} \right) \right] + \frac{(1-\phi)}{\phi} \left[\frac{\alpha}{1-\tilde{\beta}(1-\tilde{\delta})} \left(k_{i,t} - \tilde{\beta} k_{i,t+1} \right) \right]
\end{aligned} \tag{B.35}$$

Now, recall that the second-order approximation of the *overall* utility function is given by the discounted sum of the second-order approximation to the within utility functions. We can therefore pull together all of the first-order terms that remain after simplification from each within period utility function to obtain:

$$\frac{\alpha}{1-\tilde{\beta}(1-\tilde{\delta})}E_0\left[k_{j,0}-\tilde{\beta}k_{j,1}+\tilde{\beta}(k_{j,1}-\tilde{\beta}k_{j,2})+...+\tilde{\beta}^t(k_{j,t}-\tilde{\beta}k_{j,t+1})+\tilde{\beta}^{t+1}(k_{j,t+1}-\tilde{\beta}k_{j,t+2})+...\right]$$

which when we cancel terms from different periods is just equal to:

$$\frac{\alpha}{1-\tilde{\beta}(1-\tilde{\delta})}k_{j,0}$$

In other words, all linear terms in the square brackets in (B.35) disappear except for a term in $k_{j,0}$, for $j=\{c,i\}$, which denote the initial sectoral capital stocks and are assumed to be fixed and independent of policy.

Thus, the welfare function under sticky prices, (B.30), can be rewritten as:

$$\begin{aligned}\mathbb{W}_t \simeq\ & \mathbb{U}-\mathbb{V}^c+\frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\left(1-\sigma\right)c^2-\frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_c}{1+\theta_c}\right)var_f y_c(f)\\ & -\frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)(c-z_c-\alpha k_c)^2\right]-\mathbb{V}^i-\frac{1}{2}\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_i}{1+\theta_i}\right)var_f y_i(f)\\ & -\frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)(i-z_i-\alpha k_i)^2\right]\end{aligned} \tag{B.36}$$

and, the corresponding flexible-price welfare function reads:

$$\begin{aligned}\mathbb{W}_t^* \simeq \mathbb{U}^* - \mathbb{V}^{c*} + \frac{1}{2}\mathbb{U}_{\hat{C}^*}\hat{C}^*\left(1-\sigma\right)c^{*2} - \frac{1}{2}\mathbb{U}_{\hat{C}^*}\hat{C}^*(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(c^* - z_c - \alpha k_c\right)^2\right] \\ - \mathbb{V}^{i*} - \frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}^*}\hat{C}^*\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(i^* - z_i - \alpha k_i\right)^2\right]\end{aligned} \tag{B.37}$$

A few things to note are as follows. First, the terms involving sectoral outputs dispersion are nil in the flexible-price equilibrium because all firms set the same price. Second, under the Woodford's definition of natural rate beginning of period sectoral capital stocks are identical to the beginning of period sectoral capital stocks under sticky prices. In other words, the assumption is that when we enter period $t+i$, it is the capital stock that is actually present, k_{t+i-1} that determines how in i^*_{t+i} is defined; hence, in $t+i$ the capital law of motion in the flexible price economy will read:

$$k^*_{j,t+i} = (1-\tilde{\delta})k_{j,t+i-1} + \tilde{\delta}i^*_{j,t+i}$$

Subtract the flexible price equilibrium, (B.36), to the sticky price one, (B.37):

$$\begin{aligned}\mathbb{W}_t - \mathbb{W}_t^* \simeq & \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\left(1-\sigma\right)c^2 - \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_c}{1+\theta_c}\right)var_f y_c(f) \\ & - \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(c - z_c - \alpha k_c\right)^2\right] \\ & + \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(c^* - z_c - \alpha k_c\right)^2\right] - \frac{1}{2}\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_i}{1+\theta_i}\right)var_f y_i(f) \\ & - \frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(i - z_i - \alpha k_i\right)^2\right] \\ & + \frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(i^* - z_i - \alpha k_i\right)^2\right]\end{aligned} \tag{B.38}$$

Since the steady state of the sticky-price model is undistorted, the steady state terms cancel out. Also, terms involving only flexible-price variables or exogenous disturbances can be omitted since these are independent of policy (in fact these can be added and subtracted).

Equation (B.38) can be rewritten as:

$$\begin{aligned}
\mathbb{W}_t - \mathbb{W}_t^* \simeq\ & \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\,(1-\sigma)\,c^2 - \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_c}{1+\theta_c}\right) var_f y_c(f) \\
& - \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(c^2 - 2(z_c+\alpha k_c)c\right)\right] \\
& + \frac{1}{2}\mathbb{U}_{\hat{C}}\hat{C}(1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(-2(z_c+\alpha k_c)c^*\right)\right] - \frac{1}{2}\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\left(\frac{\theta_i}{1+\theta_i}\right) var_f y_i(f) \\
& - \frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(i^2 - 2(z_i+\alpha k_i)i\right)\right] \\
& + \frac{1}{2}\left[\frac{1-\phi}{\phi}\mathbb{U}_{\hat{C}}\hat{C}\right](1+\eta)\left[\left(\frac{1}{1-\alpha}\right)\left(-2(z_i+\alpha k_i)i^*\right)\right]
\end{aligned} \tag{B.39}$$

Note that terms involving differences between sticky-price and flexible-price *beginning-of-period* capital stocks cancel out, given that these two are the same.

By using Equations (B.11) and (B.12) to substitute out for the terms involving exogenous disturbances in the cross-product terms in (B.39) and divide both sides by $\mathbb{U}_{\hat{C}}\hat{C}$, one obtains:

$$\begin{aligned}
\frac{\mathbb{W}_t - \mathbb{W}_t^*}{\mathbb{U}_{\hat{C}}\hat{C}} \simeq\ & -\frac{1}{2}\left[\frac{(1+\eta)}{1-\alpha} - (1-\sigma)\right](c-c^*)^2 \\
& - \frac{1}{2}\left[\frac{1-\phi}{\phi}\right]\left(\frac{1+\eta}{1-\alpha}\right)(i-i^*)^2 - \frac{1}{2}\left(\frac{\theta_c}{1+\theta_c}\right) var_f y_c(f) \\
& - \frac{1}{2}\frac{1-\phi}{\phi}\left(\frac{\theta_i}{1+\theta_i}\right) var_f y_i(f) + \left[\frac{1-\phi}{\phi}(1+\eta)\right](h_i^*)(i-i^*)
\end{aligned} \tag{B.40}$$

Also, Woodford (2003, Chapter 6) shows that the terms involving the variance of output dispersion are proportional to the variance of price dispersion, and in turn to the variance of inflation. That is, for $j = \{c, i\}$

$$var_f y_j(f) = \left(\frac{1-\tilde{\beta}\xi_j}{1-\xi_j}\right)\frac{1}{\kappa_j}var(\pi_j)$$

where $\kappa_j = \frac{(1-\tilde{\beta}\xi_j)(1-\xi_j)}{\xi_j}$. Also, when summing over infinite time the terms involving the squared gaps are nothing but the variance of the relative gaps. Therefore, the resulting welfare function is:

$$\begin{aligned}\frac{E_0 \int_0^1 \left[\sum_{t=0}^{\infty} \tilde{\beta}^t (\mathbb{W}_t(h) - \mathbb{W}_t^*(h))\right] dh}{\mathbb{U}_C C} \simeq & -\frac{1}{2}\left[\frac{(1+\eta)}{1-\alpha} - (1-\sigma)\right] var\,(c - c^*) \\ & - \frac{1}{2}\left[\frac{1-\phi}{\phi}\left(\frac{1+\eta}{1-\alpha}\right)\right] var(i - i^*) \\ & - \frac{1}{2}\left(\frac{\theta_c}{1+\theta_c}\right)\left(\frac{1-\tilde{\beta}\xi_c}{1-\xi_c}\right)\frac{1}{\kappa_c}var(\pi_c) \\ & - \frac{1}{2}\frac{1-\phi}{\phi}\left(\frac{\theta_i}{1+\theta_i}\right)\left(\frac{1-\tilde{\beta}\xi_i}{1-\xi_i}\right)\frac{1}{\kappa_i}var(\pi_i) \\ & + \left[\frac{1-\phi}{\phi}(1+\eta)\right] cov(h_i^*, i - i^*)\end{aligned} \tag{B.41}$$

which is Equation (2.18) in Section 2.4.

Appendix C

Information Acquisition and Self-fulfilling Business Cycles

C.1 Detailed derivations of the model

The production function of firm i can be written as:

$$Y_{i,t} = A_{i,t}A_t\left(\frac{K_t}{N_t}\right)^{\alpha}N_{i,t} \tag{C.1}$$

Recall that the demand function reads:

$$Y_{i,t} = P_{i,t}^{-\theta}Y_t \tag{C.2}$$

and the optimal price setting solution is:

$$P_{i,t} = \frac{\theta}{\theta - 1} \mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right) C(W_t, R_t, A_t) \tag{C.3}$$

Use Eqs. (3.5) and (C.3) into Eq. (C.1):

$$\left(\frac{\theta}{\theta - 1} \right)^{-\theta} \left[\mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right) \right]^{-\theta} \left(\frac{1}{A_{i,t}} \right) \left[C(W_t, R_t, A_t) \right]^{-\theta} Y_t = A_t \left(\frac{K_t}{N_t} \right)^{\alpha} N_{i,t} \tag{C.4}$$

Recall that the zero profit condition in the final-good sector is:

$$\left(\int_0^1 P_{i,t} Y_{i,t} di = Y_t \right) \tag{C.5}$$

Use Eqs. (3.5) and (C.3) into Eq. (C.5):

$$C(W_t, R_t, A_t) = \left(\frac{\theta - 1}{\theta} \right) \left(\int_0^1 \mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right)^{1-\theta} di \right)^{\frac{1}{\theta - 1}} \tag{C.6}$$

Use (C.6) into (C.4):

$$\left(\int_0^1 \mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right)^{1-\theta} di \right)^{\frac{\theta}{1-\theta}} \left[\mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right) \right]^{-\theta} \left(\frac{1}{A_{i,t}} \right) Y_t = A_t \left(\frac{K_t}{N_t} \right)^{\alpha} N_{i,t} \tag{C.7}$$

Sum over i on both sides:

$$Y_t \left(\int_0^1 \mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right)^{1-\theta} \mathrm{d}i \right)^{\frac{\theta}{1-\theta}} \int_0^1 \left[\mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right) \right]^{-\theta} \left(\frac{1}{A_{i,t}} \right) \mathrm{d}i = A_t \left(\frac{K_t}{N_t} \right)^{\alpha} \int_0^1 N_{i,t} \mathrm{d}i \tag{C.8}$$

Note that:

$$\int_0^1 \left[\mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right) \right]^{-\theta} \left(\frac{1}{A_{i,t}} \right) \mathrm{d}i = \int_0^1 \left[\mathrm{E}_{i,t} \left(\frac{1}{A_{i,t}} \right) \right]^{1-\theta} \mathrm{d}i$$

Thus, one can obtain Eq. (3.10) in the main text.

C.2 Consumer confidence index and sunspot shocks

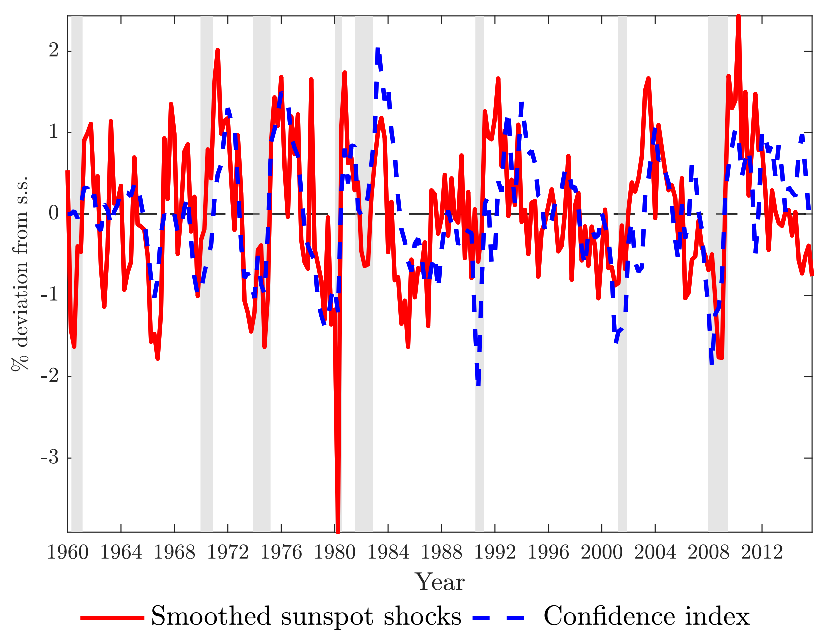


Figure C.2.1: Consumer confidence index and sunspot shocks
Note: Consumer confidence represents the OECD Confidence Indicator for the United States. I eliminate its trend using a one-sided HP filter.

Bibliography

Akinci, Ozge. 2013. "Global financial conditions, country spreads and macroeconomic fluctuations in emerging countries." *Journal of International Economics*, 91(2): 358–371.

Alpanda, Sami, and Uluc Aysun. 2014. "International transmission of financial shocks in an estimated DSGE model." *Journal of International Money and Finance*, 47(C): 21–55.

Alvarez, Luis J., Emmanuel Dhyne, Marco Hoeberichts, Claudia Kwapil, Hervé Le Bihan, Patrick Lünnemann, Fernando Martins, Roberto Sabbatini, Harald Stahl, Philip Vermeulen, and Jouko Vilmunen. 2006. "Sticky Prices in the Euro Area: A Summary of New Micro-Evidence." *Journal of the European Economic Association*, 4(2-3): 575–584.

Angeletos, George-Marios, and Alessandro Pavan. 2007. "Efficient Use of Information and Social Value of Information." *Econometrica*, 75(4): 1103–1142.

Bibliography

Aoki, Kosuke. 2001. "Optimal monetary policy responses to relative-price changes." *Journal of Monetary Economics*, 48(1): 55–80.

Ascari, Guido. 2004. "Staggered Prices and Trend Inflation: Some Nuisances." *Review of Economic Dynamics*, 7(3): 642–667.

Bachmann, Rudiger, Steffen Elstner, and Eric R. Sims. 2013. "Uncertainty and Economic Activity: Evidence from Business Survey Data." *American Economic Journal: Macroeconomics*, 5(2): 217–49.

Backus, David K., Federico Gavazzoni, Christopher Telmer, and Stanley E. Zin. 2010. "Monetary Policy and the Uncovered Interest Parity Puzzle." National Bureau of Economic Research, Inc NBER Working Papers 16218.

Barsky, Robert B., and Eric R. Sims. 2011. "News shocks and business cycles." *Journal of Monetary Economics*, 58(3): 273–289.

Barsky, Robert B., Christopher L. House, and Miles S. Kimball. 2007. "Sticky-Price Models and Durable Goods." *American Economic Review*, 97(3): 984–998.

Barsky, Robert, Christoph E. Boehm, Christopher L. House, and Miles Kimball. 2016. "Monetary Policy and Durable Goods." Federal Reserve Bank of Chicago Working Paper Series WP-2016-18.

Basu, S., and C.L. House. 2016. "Allocative and Remitted Wages: New Facts and Challenges for Keynesian Models." In *Handbook of Macroeconomics*. Vol. 2, , ed. John B. Taylor and Harald Uhlig, Chapter 6, 297 – 354. Elsevier.

Basu, Susanto, and John Fernald. 2001. "Why Is Productivity Procyclical? Why Do We Care?" In *New Developments in Productivity Analysis. NBER Chapters*, 225–302. National Bureau of Economic Research, Inc.

Basu, Susanto, and John G. Fernald. 1997. "Returns to Scale in U.S. Production: Estimates and Implications." *Journal of Political Economy*, 105(2): 249–83.

Basu, Susanto, John G. Fernald, and Zheng Liu. 2014. "Technology shocks in a two-sector DSGE model." In . Manuscript.

Basu, Susanto, John G. Fernald, Jonas D. M. Fisher, and Miles S. Kimball. 2013. "Sector-specific technical change." In . Manuscript, Federal Reserve Bank of San Francisco.

Beaudry, Paul, and Franck Portier. 2014. "News-Driven Business Cycles: Insights and Challenges." *Journal of Economic Literature*, 52(4): 993–1074.

Benhabib, Jess, and Pengfei Wang. 2013. "Financial constraints, endogenous markups, and self-fulfilling equilibria." *Journal of Monetary Economics*, 60(7): 789–805.

Benhabib, Jess, and Roger Farmer. 1994. "Indeterminacy and Increasing Returns." *Journal of Economic Theory*, 63(1): 19–41.

Benhabib, Jess, Feng Dong, and Pengfei Wang. 2014. "Adverse Selection and Self-fulfilling Business Cycles." National Bureau of Economic Research, Inc NBER Working Papers 20642.

Benhabib, Jess, Xuewen Liu, and Pengfei Wang. 2016. "Endogenous information acquisition and countercyclical uncertainty." *Journal of Economic Theory*, 165(C): 601–642.

Benigno, Pierpaolo. 2004. "Optimal monetary policy in a currency area." *Journal of International Economics*, 63(2): 293–320.

Ben-Zeev, Nadav, Evi Pappa, and Alejandro Vicondoa. 2016. "Emerging Economies Business Cycles: The Role Of The Terms Of Trade Revisited."

Bernanke, Ben S. 2015. "The Taylor Rule: A benchmark for monetary policy?" *Brookings Institution.* http://www.brookings.edu/blogs/ben-bernanke/posts/2015/04/28-taylor-rule-monetary-policy.

Bernanke, Ben S., Thomas Laubach, Frederic S. Mishkin, and Adam S. Posen. 1999. "Inflation targeting: lessons from the international experience." In . Princeton University Press, Princeton NJ.

Bhattarai, Saroj, Arpita Chatterjee, and Woong Yong Park. 2017. "Global Spillover Effects of US Uncertainty." School of Economics, The University of New South Wales Discussion Papers 2017-17.

Blanchard, Olivier. 2004. "Fiscal Dominance and Inflation Targeting: Lessons from Brazil." National Bureau of Economic Research, Inc NBER Working Papers 10389.

Blanchard, Olivier, and Jordi Galí. 2007. "Real Wage Rigidities and the New Keynesian Model." *Journal of Money, Credit and Banking*, 39(s1): 35–65.

Bruno, Valentina, and Hyun Song Shin. 2015. "Capital flows and the risk-taking channel of monetary policy." *Journal of Monetary Economics*, 71(C): 119–132.

Calvo, Guillermo A. 1983. "Staggered prices in a utility-maximizing framework." *Journal of Monetary Economics*, 12(3): 383–398.

Calvo, Guillermo A., and Carmen M. Reinhart. 2002. "Fear of Floating." *The Quarterly Journal of Economics*, 117(2): 379–408.

Canova, Fabio. 2005. "The transmission of US shocks to Latin America." *Journal of Applied Econometrics*, 20(2): 229–251.

Carrillo, Julio A., and Rocío Elizondo. 2015. "How Robust Are SVARs at Measuring Monetary Policy in Small Open Economies?" Banco de México Working Papers 2015-18.

Carvalho, Carlos. 2006. "Heterogeneity in Price Stickiness and the Real Effects of Monetary Shocks." *The B.E. Journal of Macroeconomics*, 6(3): 1–58.

Cavallino, Paolo. Forthcoming. "Capital Flows and Foreign Exchange Intervention." *American Economic Journal: Macroeconomics*.

Cesa-Bianchi, Ambrogio, Andrea Ferrero, and Alessandro Rebucci. 2018. "International credit supply shocks." *Journal of International Economics*, 112(C): 219–237.

Chahrour, Ryan, and Gaetano Gaballo. 2017. "Learning from prices: amplication and business fluctuations." European Central Bank Working Paper Series 2053.

Chamley, Christophe. 1986. "Optimal Taxation of Capital Income in General Equilibrium with Infinite Lives." *Econometrica*, 54(3): 607–22.

Clarida, Richard, and Jordi Gali. 1994. "Sources of real exchange-rate fluctuations: How important are nominal shocks?" *Carnegie-Rochester Conference Series on Public Policy*, 41(1): 1–56.

Coeurdacier, Nicolas, Hélène Rey, and Pablo Winant. 2011. "The Risky Steady State." *American Economic Review*, 101(3): 398–401.

Colombo, Luca, Gianluca Femminis, and Alessandro Pavan. 2014. "Information Acquisition and Welfare." *Review of Economic Studies*, 81(4): 1438–1483.

Cushman, David O., and Tao Zha. 1997. "Identifying monetary policy in a small open economy under flexible exchange rates." *Journal of Monetary Economics*, 39(3): 433–448.

David, Joel M., Hugo A. Hopenhayn, and Venky Venkateswaran. 2016. "Information, Misallocation, and Aggregate Productivity." *The Quarterly Journal of Economics*, 131(2): 943–1005.

Davis, Scott, and Andrei Zlate. 2017. "Monetary Policy Divergence, Net Capital Flows, and Exchange Rates: Accounting for Endogenous Policy Responses." Federal Reserve Bank of Dallas Globalization and Monetary Policy Institute Working Paper 328.

Della Corte, Pasquale, Steven J. Riddiough, and Lucio Sarno. 2016. "Currency Premia and Global Imbalances." *Review of Financial Studies*, 29(8): 2161–2193.

De Paoli, Bianca. 2009. "Monetary policy and welfare in a small open economy." *Journal of International Economics*, 77(1): 11–22.

di Giovanni, Julian, Sebnem Kalemli-Ozcan, Mehmet Fatih Ulu, and Yusuf Soner Baskaya. 2017. "International Spillovers and Local Credit Cycles." National Bureau of Economic Research, Inc NBER Working Papers 23149.

Dornbusch, Rudiger. 1976. "Expectations and Exchange Rate Dynamics." *Journal of Political Economy*, 84(6): 1161–1176.

Edge, Rochelle M. 2003. "A utility-based welfare criterion in a model with endogenous capital accumulation." In . Finance and Economics Discussion Series No. 2003-66, Board of Governors of the Federal Reserve System.

Eichenbaum, Martin, and Charles L. Evans. 1995. "Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates." *The Quarterly Journal of Economics*, 110(4): 975–1009.

Engel, Charles. 2016. "Exchange Rates, Interest Rates, and the Risk Premium." *American Economic Review*, 106(2): 436–474.

Erceg, Christopher J., and Andrew T. Levin. 2006. "Optimal monetary policy with durable consumption goods." *Journal of Monetary Economics*, 53(7): 1341–1359.

Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin. 2000. "Optimal monetary policy with staggered wage and price contracts." *Journal of Monetary Economics*, 46(2): 281–313.

Farmer, Roger E.A., Vadim Khramov, and Giovanni Nicolò. 2015. "Solving and estimating indeterminate DSGE models." *Journal of Economic Dynamics and Control*, 54(C): 17–36.

Faust, Jon. 1998. "The robustness of identified VAR conclusions about money."

Faust, Jon, and John H. Rogers. 2003. "Monetary policy's role in exchange rate behavior." *Journal of Monetary Economics*, 50(7): 1403–1424.

Fernández, Andrés, Stephanie Schmitt-Grohé, and Martin Uribe. 2016. "World Shocks, World Prices, and Business Cycles: An Empirical Investigation." In *NBER International Seminar on Macroeconomics 2016. NBER Chapters.* National Bureau of Economic Research, Inc.

Fisher, Jonas D. M. 2006. "The Dynamic Effects of Neutral and Investment-Specific Technology Shocks." *Journal of Political Economy*, 114(3): 413–451.

Forni, Mario, and Luca Gambetti. 2014. "Sufficient information in structural VARs." *Journal of Monetary Economics*, 66(C): 124–136.

Foster, Lucia, John Haltiwanger, and Chad Syverson. 2008. "Reallocation, Firm Turnover, and Efficiency: Selection on Productivity or Profitability?" *American Economic Review*, 98(1): 394–425.

Francis, Neville, Michael T. Owyang, Jennifer E. Roush, and Riccardo DiCecio. 2014. "A Flexible Finite-Horizon Alternative to Long-Run Restrictions with an Application to Technology Shocks." *The Review of Economics and Statistics*, 96(4): 638–647.

Frankel, Jeffrey. 2010. "Monetary policy in emerging markets." In *Handbook of monetary economics.* Vol. 3, 1439–1520. Elsevier.

Gabaix, Xavier, and Matteo Maggiori. 2015. "International Liquidity and Exchange Rate Dynamics." *The Quarterly Journal of Economics*, 130(3): 1369–1420.

Galí, Jordi, and Tommaso Monacelli. 2005. "Monetary Policy and Exchange Rate Volatility in a Small Open Economy." *Review of Economic Studies*, 72(3): 707–734.

Georgiadis, Georgios, and Martina Jancoková. 2017. "Financial globalisation, monetary policy spillovers and macro-modelling: tales from 1001 shocks." European Central Bank Working Paper Series 2082.

Gondhi, Naveen. 2015. "Rational Inattention, Misallocation, and Asset Prices." Working Paper.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W Huffman. 1988. "Investment, Capacity Utilization, and the Real Business Cycle." *American Economic Review*, 78(3): 402–17.

Greenwood, Jeremy, Zvi Hercowitz, and Per Krusell. 2000. "The role of investment-specific technological change in the business cycle." *European Economic Review*, 44(1): 91–115.

Guerron-Quintana, Pablo A. 2013. "Common and idiosyncratic disturbances in developed small open economies." *Journal of International Economics*, 90(1): 33–49.

Hamilton, James D. 1994. *Time Series Analysis.* Princeton University Press.

Hansen, Gary D. 1985. "Indivisible labor and the business cycle." *Journal of Monetary Economics*, 16(3): 309–327.

Hassan, Tarek A. 2013. "Country Size, Currency Unions, and International Asset Returns." *Journal of Finance*, 68(6): 2269–2308.

Hellwig, Christian, and Laura Veldkamp. 2009. "Knowing What Others Know: Coordination Motives in Information Acquisition." *Review of Economic Studies*, 76(1): 223–251.

Hellwig, Christian, Sebastian Kohls, and Laura Veldkamp. 2012. "Information Choice Technologies." *American Economic Review*, 102(3): 35–40.

Herbst, Edward P., and Frank Schorfheide. 2016. *Bayesian Estimation of DSGE Models. Economics Books*, Princeton University Press.

Hnatkovska, Viktoria, Amartya Lahiri, and Carlos A. Vegh. 2016. "The Exchange Rate Response to Monetary Policy Innovations." *American Economic Journal: Macroeconomics*, 8(2): 137–81.

Hsieh, Chang-Tai, and Peter J. Klenow. 2009. "Misallocation and Manufacturing TFP in China and India." *The Quarterly Journal of Economics*, 124(4): 1403–1448.

Huang, Kevin X.D., and Zheng Liu. 2005. "Inflation targeting: What inflation rate to target?" *Journal of Monetary Economics*, 52(8): 1435–1462.

Iacoviello, Matteo, and Gaston Navarro. 2018. "Foreign effects of higher U.S. interest rates." *Journal of International Money and Finance.*

Ikeda, Daisuke. 2015. "Optimal inflation rates with the trending relative price of investment." *Journal of Economic Dynamics and Control*, 56(C): 20–33.

Ilzetzki, Ethan, Carmen M. Reinhart, and Kenneth S. Rogoff. 2017. "The Country Chronologies to Exchange Rate Arrangements into the 21st Century: Will the Anchor Currency Hold?" National Bureau of Economic Research, Inc NBER Working Papers 23135.

Itskhoki, Oleg, and Dmitry Mukhin. 2017. "Exchange Rate Disconnect in General Equilibrium." National Bureau of Economic Research, Inc NBER Working Papers 23401.

Jääskelä, Jarkko P., and David Jennings. 2011. "Monetary policy and the exchange rate: Evaluation of VAR models." *Journal of International Money and Finance*, 30(7): 1358–1374.

Jeanne, Olivier, and Andrew K. Rose. 2002. "Noise Trading and Exchange Rate Regimes." *The Quarterly Journal of Economics*, 117(2): 537–569.

Justiniano, Alejandro, and Bruce Preston. 2010. "Can structural small open-economy models account for the influence of foreign disturbances?" *Journal of International Economics*, 81(1): 61–74.

Justiniano, Alejandro, Giorgio E. Primiceri, and Andrea Tambalotti. 2010. "Investment shocks and business cycles." *Journal of Monetary Economics*, 57(2): 132–145.

Kehrig, Matthias. 2011. "The Cyclicality of Productivity Dispersion." Center for Economic Studies, U.S. Census Bureau Working Papers 11-15.

Kilian, Lutz. 1998. "Small-Sample Confidence Intervals for Impulse Response Functions." *The Review of Economics and Statistics*, 80(2): 218–230.

Kim, Soyoung, and Nouriel Roubini. 2000. "Exchange rate anomalies in the industrial countries: A solution with a structural VAR approach." *Journal of Monetary Economics*, 45(3): 561–586.

Kohlscheen, Emanuel. 2014. "The impact of monetary policy on the exchange rate: A high frequency exchange rate puzzle in emerging economies." *Journal of International Money and Finance*, 44: 69–96.

Landauer, Thomas K. 1986. "How much Do People Remember? Some Estimates of the Quantity of Learned Information in Long-term Memory." *Cognitive Science*, 10(4): 477–493.

Lane, Philip R., and Gian Maria Milesi-Ferretti. 2007. "The external wealth of nations mark II: Revised and extended estimates of foreign assets and liabilities, 1970-2004." *Journal of International Economics*, 73(2): 223–250.

Levchenko, Andrei A., and Nitya Pandalai-Nayar. 2015. "TFP, News, and 'Sentiments:' The International Transmission of Business Cycles." National Bureau of Economic Research, Inc NBER Working Papers 21010.

Liu, Zheng, and Pengfei Wang. 2014. "Credit Constraints and Self-Fulfilling Business Cycles." *American Economic Journal: Macroeconomics*, 6(1): 32–69.

Llosa, Luis Gonzalo, and Venky Venkateswaran. 2015. "Efficiency with Endogenous Information Choice." Peruvian Economic Association Working Papers 2015-44.

Lustig, Hanno, Nikolai Roussanov, and Adrien Verdelhan. 2011. "Common Risk Factors in Currency Markets." *Review of Financial Studies*, 24(11): 3731–3777.

Mackowiak, Bartosz. 2007. "External shocks, U.S. monetary policy and macroeconomic fluctuations in emerging markets." *Journal of Monetary Economics*, 54(8): 2512–2520.

Mackowiak, Bartosz, and Mirko Wiederholt. 2009. "Optimal Sticky Prices under Rational Inattention." *American Economic Review*, 99(3): 769–803.

Maggiori, Matteo. 2017. "Financial Intermediation, International Risk Sharing, and Reserve Currencies." *American Economic Review*, 107(10): 3038–71.

Mankiw, N. Gregory, and Ricardo Reis. 2003. "What Measure of Inflation Should a Central Bank Target?" *Journal of the European Economic Association*, 1(5): 1058–1086.

Monacelli, Tommaso. 2004. "Into the Mussa puzzle: monetary policy regimes and the real exchange rate in a small open economy." *Journal of International Economics*, 62(1): 191–217.

Moura, Alban. 2018. "Investment Shocks, Sticky Prices, and the Endogenous Relative Price of Investment." *Review of Economic Dynamics*, 27: 48–63.

Mäkinen, Taneli, and Björn Ohl. 2015. "Information acquisition and learning from prices over the business cycle." *Journal of Economic Theory*, 158(PB): 585–633.

Nakamura, Emi, and Jón Steinsson. 2008. "Five Facts about Prices: A Reevaluation of Menu Cost Models." *The Quarterly Journal of Economics*, 123(4): 1415–1464.

Neiss, Katharine S., and Edward Nelson. 2003. "The Real-Interest-Rate Gap As An Inflation Indicator." *Macroeconomic Dynamics*, 7(02): 239–262.

Obstfeld, Maurice, and Kenneth Rogoff. 1995. "Exchange Rate Dynamics Redux." *Journal of Political Economy*, 103(3): 624–60.

Pavan, Alessandro, and George-Marios Angeletos. 2013. "Selection-free predictions in global games with endogenous information and multiple equilibria." *Theoretical Economics*, 8(3).

Pavlov, Oscar, and Mark Weder. 2017. "Product Scope and Endogenous Fluctuations." *Review of Economic Dynamics*, 24: 175–191.

Ramey, Garey, and Valerie A Ramey. 1995. "Cross-Country Evidence on the Link between Volatility and Growth." *American Economic Review*, 85(5): 1138–51.

Ready, ROBERT, NIKOLAI Roussanov, and COLIN Ward. 2017. "Commodity Trade and the Carry Trade: A Tale of Two Countries." *The Journal of Finance*, 72(6): 2629–2684.

Reinhart, Carmen M., and Kenneth S. Rogoff. 2004. "The Modern History of Exchange Rate Arrangements: A Reinterpretation." *The Quarterly Journal of Economics*, 119(1): 1–48.

Reis, Ricardo. 2006. "Inattentive Producers." *Review of Economic Studies*, 73(3): 793–821.

Rey, Hélène. 2015. "Dilemma not Trilemma: The global Financial Cycle and Monetary Policy Independence." National Bureau of Economic Research, Inc NBER Working Papers 21162.

Rogerson, Richard. 1988. "Indivisible labor, lotteries and equilibrium." *Journal of Monetary Economics*, 21(1): 3–16.

Rotemberg, Julio J., and Michael Woodford. 1997. "An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy." In *NBER Macroeconomics Annual 1997.* ed. B. S. Bernanke and J. J. Rotemberg, MIT Press, vol. 12, 297–346.

Scholl, Almuth, and Harald Uhlig. 2008. "New evidence on the puzzles: Results from agnostic identification on monetary policy and exchange rates." *Journal of International Economics*, 76(1): 1–13.

Senga, Tatsuro. 2015. "A New Look at Uncertainty Shocks: Imperfect Information and Misallocation." Queen Mary University of London, School of Economics and Finance Working Papers 763.

Sims, Christopher A., and Tao Zha. 2006. "Does Monetary Policy Generate Recessions?" *Macroeconomic Dynamics*, 10(02): 231–272.

Smets, Frank, and Rafael Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review*, 97(3): 586–606.

Straub, Ludwig, and Robert Ulbricht. 2015. "Endogenous Uncertainty and Credit Crunches." Toulouse School of Economics (TSE) TSE Working Papers 15-604.

Sveen, Tommy. 2014. "Capital accumulation, sectoral heterogeneity and the Taylor principle." *Journal of Economic Dynamics and Control*, 44(C): 20–28.

Svensson, Lars E. O. 2010. "Inflation Targeting." In *Handbook of Monetary Economics.* Vol. 3, , ed. Benjamin M. Friedman and Michael Woodford, Chapter 22, 1237–1302. Elsevier.

Svensson, Lars E. O., and Leonardo Leiderman. 1995. "Inflation Targets." In . Centre for Economic Policy and Research, London.

Taylor, John B. 1993. "Discretion versus policy rules in practice." *Carnegie-Rochester Conference Series on Public Policy*, 39(1): 195–214.

Uhlig, Harald. 2004. "Do Technology Shocks Lead to a Fall in Total Hours Worked?" *Journal of the European Economic Association*, 2(2-3): 361–371.

Uribe, Martin, and Vivian Z. Yue. 2006. "Country spreads and emerging countries: Who drives whom?" *Journal of International Economics*, 69(1): 6–36.

Van Nieuwerburgh, Stijn, and Laura Veldkamp. 2006. "Learning asymmetries in real business cycles." *Journal of Monetary Economics*, 53(4): 753–772.

Veldkamp, Laura, and Justin Wolfers. 2007. "Aggregate shocks or aggregate information? Costly information and business cycle comovement." *Journal of Monetary Economics*, 54(Supplemen): 37–55.

Vermeulen, Philip, Daniel A. Dias, Maarten Dossche, Erwan Gautier, Ignacio Hernando, Roberto Sabbatini, and Harald Stahl. 2012. "Price Setting in the Euro Area: Some Stylized Facts from Individual Producer Price Data." *Journal of Money, Credit and Banking*, 44(8): 1631–1650.

Vicondoa, Alejandro. 2016. "Monetary News, U.S. Interest Rate and Business Cycles in Emerging Economies." European University Institute Economics Working Papers ECO2016/10.

Vives, Xavier. 2011. "Endogenous Public Information and Welfare." C.E.P.R. Discussion Papers CEPR Discussion Papers 8437.

Wen, Yi. 1998. "Capacity Utilization under Increasing Returns to Scale." *Journal of Economic Theory*, 81(1): 7–36.

Woodford, Michael. 2003. "Interest and prices." In . Princeton University Press, Princeton NJ.

Yun, Tack. 1996. "Nominal price rigidity, money supply endogeneity, and business cycles." *Journal of Monetary Economics*, 37(2-3): 345–370.

Zbaracki, Mark J., Mark Ritson, Daniel Levy, Shantanu Dutta, and Mark Bergen. 2004. "Managerial and Customer Costs of Price Adjustment: Direct Evidence from Industrial Markets." *The Review of Economics and Statistics*, 86(2): 514–533.