UNIVERSITEIT GENT

FACULTEIT ECONOMIE EN BEDRIJFSKUNDE

THREE ESSAYS IN DYNAMIC STOCHASTIC MACROECONOMICS

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2010

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Submitted to the Faculty of Economics and Business
Administration in partial fulfilment of the requirements for
the degree of Doctor in Economics

THREE ESSAYS IN DYNAMIC STOCHASTIC MACROECONOMICS

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Acknowledgements

A few hundred years before I enrolled in Universiteit Gent, a Genoese adventurer and his comrades took three boats out into the Atlantic, determined to unravel the first sea-route to India from the Western world. Braving several months of ill-health, inclement weather and violent mutinies, Cristoforo Colombo set foot on a tiny island he was quite convinced was just off the Indian coast. Till the day he died, Colombo was never in doubt that he had charted the sea-route to India. The world now knows that the modern-day Bahamas are a little further away from India than Colombo would have hoped.

PhDs in applied macroeconometrics are less dangerous to pursue than sea-journeys in medieval times. Nevertheless, they are potentially as unpredictable. The destination is not clearly defined. Maps rarely exist and even if they do, can rarely be followed. As I near the end of my four and a half year journey, I wonder how I would have made it without the support of some wonderful people.

Gert Peersman, my supervisor and first co-author, taught me the importance of trying to bridge the disconnect between macroeconomic theory and the data. He provided excellent supervision, both intellectual and logistical, for the successful completion of the dissertation. When the chips were down - and in PhD research, they tend to be down for seemingly unbounded stretches of time - Gert was always there with words of encouragement. Thank you, Gert!

I am indebted to Raf Wouters of the National Bank of Belgium who introduced me to the estimation of dynamic macroeconomic models. It was a privilege to work closely with him while an intern at the Bank. Without the many hours of advice I received in Raf's office, this dissertation would not have materialized. I also thank Freddy Heylen, my senior colleague at the Faculty, who has always been a source of encouragement and good advice. The quality of the dissertation has improved greatly thanks to the inputs of Roland Straub of the European Central Bank and Robert Kollmann of the *Université Libre de Bruxelles*.

Every member of the *Vakroep* has contributed to my work. They have read my papers, corrected my mistakes, questioned my conclusions and tested my presentation skills. They also joined me for lunch at *De Brug* and beers at the *Hasta Mañana*, introduced me to the finest restaurants in town and enriched my vocabulary in Dutch (which was perhaps the easiest of all their endeavours).

I have had the good fortune of studying economics in five universities in four countries across three continents. Many people I met during my travels have contributed to my growth as an academic macroeconomist and perhaps more significantly, as a person. Jenny Ligthart, my MSc supervisor at Tilburg University; Fabrice Collard and Pau Rabanal from the University of Adelaide and the International Monetary Fund; Amar Sahoo of the University College in Dublin, a constant guide and friend since my Tilburg days; Bejoy Thomas, Rejie George, Pradeep George and D. Rajasenan from my studies in India; my students and classmates at Cochin University; Mindy Mallory, Sanchita Sengupta and the Great Kerala Gang in Urbana-Champaign, Portland and Ames in the United States; my schoolmates Kishore Rajagopalan and Smitha Nair in Bangalore and Chennai; A.M. Geevarghese, Annama Vargis, Mathew Varghese, Rachel Varghese and Santhosh Shyamsundar in Aluva, Bergen, Macao and Dubai; Valsa Mannali, Jenny-Ann Lukose, Rosamma Varghese and Mini Balakrishnan in Inverness, Cochin and Calicut; my fellow cricketers Arjun Vasanth and Sangeeth Mathews in Mumbai and Calicut; Tej, Archana and Ganesh Nair in Bangalore; Nicolas Groshenny, Antonina Rasiej and their three lovely little girls in New Zealand; Giulio Nicoletti from the *Banca D'Italia*; my former and present colleagues at the Faculty, Tino Berger, Maarten Dossche, Gerdie Everaert and Dieter Verhaest; my countrymen in Belgium, Jijo and Joshua Dominic, Shalet Verghese, Sherry Kunjachan, Joseph Cherian, Archana Chacko, Bhaskar Prasad and C.V. Prakashan.

My family has always been there whenever I needed support. My parents and grandparents instilled in me a love for learning and the will to persevere. I thank my parents-in-law, my granduncle the Rev. J.M. Elanjileth, aunts Aley Jacob, Susan John and Beena Cherian, uncles J. Jacob, John Punnoose, Brian Betts and Jibu Cherian, my brother Thomas Jacob, Lisa Thomas, Anita John, Rita John, Sancho, Jebin Cherian, George Cherian and Kiron George for constant encouragement. My aunt Anna Thomas-Betts and cousin Rebecca Jacob-Pulimood gave me the right advice at the right time over the last four years. The fact that they reside close by in the United Kingdom contributed in no small measure. Even better, the advice was always supplemented with some fantastic food. Thank you, Family!

I dedicate this dissertation to my much-better half, Keerthi George. For two years, she managed work and home. Crucially, she also managed me.

Punnoose Jacob

May 2010

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Chapter 1

Introduction

1 Overview of the Dissertation

Since the pioneering work of Kydland and Prescott (1982), dynamic models with explicit optimization-based foundations have proved to be useful laboratories to understand complex macroeconomic phenomena. Within this methodological framework, generically known as dynamic stochastic general equilibrium (DSGE) modelling, business cycle movements in macroeconomic prices and quantities are the results of the optimal response of rational economic agents to random disturbances hitting the economy. The early generation of DSGE models were flexible price models that emphasized the importance of 'real' disturbances such as total factor productivity and government spending in generating business cycles. However, recent times have seen the rise of New Keynesian DSGE models (See Gali 2008) that while remaining committed to the rigorous microeconomic reasoning of Kydland and Prescott (1982), also introduced imperfect competition, incomplete nominal adjustment and consequently a role for the nominal interest rate in stimulating economic activity. Smets and Wouters (2003, 2007) have shown that New Keynesian models, augmented by a variety of real and nominal frictions and estimated with Bayesian methods can compete with the statistical fit and forecasting performance of more reduced-form models such as vector autoregressions. In fact, the statistical success of the medium-scale estimated New Keynesian DSGE model has made it an indispensable part of the central banker's toolkit.

This dissertation comprises three positive essays that enhance our understanding of the stochastic sources of business cycles and their relevant channels of transmission, through the lens of New Keynesian DSGE models. In Chapter 2, we employ a sequence of open-economy models, estimated with Bayesian methods, to unravel the stuctural disturbances that drive fluctuations in the US trade balance. In contrast, Chapter 3 is purely theoretical and focusses on the comovement between public and private consumption observed in the environment characterized by good-specific habit formation in a closed economy as in Ravn, Schmitt-Grohé and Uribe (2006). In Chapter 4, the analysis returns to the open-economy setting and we disaggregate the dynamics of the Canada-US real exchange rate into movements in the domestic and international prices it subsumes, again within the environs of an estimated DSGE model. The remainder of this introductory chapter is organized as follows. In Sections 2, 3 and 4, we examine the contributions of each essay in greater detail. Finally, in Section 5, we outline a few ideas to be pursued in future research.

2 The Dynamics of the US Trade Balance

Chapter 2 involves models that fall in the sub-strand of the New Keynesian literature addressing the international dimension of economies and is known as the New Open Economy Macroeconomics (NOEM). Effectively, the NOEM bridges three distinct literatures in international economics: the classic Mundell-Fleming model of macroeconomic fluctuations, traditional static trade theory as well as the international real business cycle (RBC) literature exemplified by the work of Backus, Kydland and Kehoe (1994). While the NOEM shares the Keynesian intellectual foundation of imperfect competition and sticky prices with the Mundell-Fleming model, it is most intimately related to the international RBC literature due to its focus on dynamic optimization. Critically, openness enable economic agents to trade internationally in financial assets and goods and insure themselves against consumption risk in the face of domestic shocks. This leads to the inter-temporal determination of two variables: the current account and the real exchange rate.

This essay, coauthored with Gert Peersman, focusses on the trade balance, the dominant component of the current account. Specifically, we offer an empirical analysis of the stochastic disturbances that drive fluctuations in the US trade deficit, the preeminent indicator of contemporary global financial imbalances. We estimate a sequence of NOEM two-country models with Bayesian methods and examine the effects of a variety of domestic and foreign disturbances, from the demand- as well as the supply-side on the US business cycle, focussing on the trade balance (net exports) in particular. The baseline model that we employ can be seen as a two-country version of the closed economy models described in Smets and Wouters (2003, 2007), where the second 'country' is a trade-weighted aggregate of sixteen OECD partners with whom the US has experienced deficits for a reasonably long span of time. The estimation is based on quarterly data spanning 1980-2005.

Our results highlight the relative importance of investment-specific technological shocks, that increase the efficiency of conversion of investment into the capital stock, in understanding the cyclical behavior of the trade balance. In most of our specifications, domestic and foreign investment-specific shocks, in unison, contribute more than half the forecast-volatility of the trade balance. This is quite in contrast to the extant theoretical literature that attribute the dynamics of the trade balance to neutral technological shocks, such as total factor productivity. We find that while investment-specific shocks have a substantial negative effect on the trade balance, the neutral shock even improves the trade balance.

Interesting insights emerge from the split-up of the trade balance into the net-export volumes, *i.e.* differentials between foreign and home consumption and investment quantities, and the effect from the relative prices or in the other words, the expenditure-switching effect in favor of US exports that arises from the deterioration of the US terms of trade.

The crux of the differential impact lies in the ability of the investment-specific shock to elicit a strong response from the net-export *volumes*. Even though the neutral shock exerts a weak negative impact on the trade balance by raising domestic consumption and investment, the overall influence on the trade balance is determined by the positive expenditure-switching effect induced by the fall in the price of US goods. This effect even makes the trade balance behave procyclically in the short- and medium-run. The procyclicality of the trade balance runs against the received wisdom in the literature that emphasizes its counter-cyclical nature. In contrast, the rise in US investment induced by the investment-specific shock leads to a fall in net traded volumes that is robust enough to dominate the positive expenditure-switching effect, generating a decline in the trade balance. The dominance of the investment-specific shock is not a surprise as US exports and imports are heavily concentrated in capital goods and consumer durables. Whereas the impact of both technology shocks on total output is of a similar magnitude, investment-specific shocks have a more powerful positive impact on US investment. As a consequence, there is a substantial fall in relative investment net export volumes which strongly deteriorates the overall trade balance. The counter-cyclical trade balance dynamics triggered by the investment shock makes it more appealing than the neutral shock as a stochastic driver of trade deficits.

3 The Comovement of Public and Private Consumption

Unlike Chapter 2, Chapter 3 is purely theoretical and is set in a closed-economy environment. Many empirical studies report that fiscal expansions have a positive effect on private consumption. The standard model of macroeconomic fluctuations that emphasizes inter-temporally optimizing agents cannot generate this response. A rise in unproductive government spending generates, *ceteris paribus*, a concurrent increase in the present value of lumpsum taxes. This negative wealth effect induced by the fiscal expansion results in the lowering of private consumption, a phenomenon known in the literature as 'crowding-out'.

In this essay, we examine the economic environment featuring '*deep*' (good-specific) habits used by Ravn, Schmitt-Grohé and Uribe (2006) to generate the positive comovement between public and private consumption. In their set-up, habit formation at the level of individual differentiated goods varieties makes the demand function facing the price-setting firm, dynamic. This is in contrast to the traditional scheme of habit formation at the level of the aggregate good, which is a constant elasticity composite of the individual varieties, as in Smets and Wouters (2003, 2007), where the demand function facing the intermediate goods firm is static. The dynamic component in the demand for the individual varieties, makes it optimal for the firms to lower mark-ups of prices over nominal marginal costs when they expand production in response to the fiscal expansion, leading to an increase in the demand for labor and hence the real wage rises. The consequent intra-temporal substitution of consumption for leisure triggers the positive response of consumption.

The central contribution of this essay is the finding that the ‘crowding-in’ that Ravn, Schmitt-Grohé and Uribe (2006) observe is contingent on their assumption that prices and wages are perfectly flexible. Starting from their original specification (and parameterization) with flexible prices and wages, we sequentially add higher degrees of nominal rigidities, first in price and then in wage adjustment. In the presence of nominal rigidities, the mark-up and the real wage cease to move substantially in response to fiscal shocks and consequently consumption is still crowded out as in a standard forward-looking model.

The observed ineffectiveness of the deep habits set-up to generate the positive comovement under more realistic conditions runs parallel to the empirical fragility of another mechanism that the theoretical literature employs to generate the rise in consumption to the fiscal expansion. Specifically, Galí, López-Salido and Vallés (2007) use credit-constrained consumers who do not smooth consumption and simply consume their after-tax wage income. If prices are sticky and labor markets are imperfectly competitive, the real wage rises after the fiscal shock. Since the credit-constrained agent is insulated from the negative wealth-effect of the fiscal expansion, the positive impact of the rise in the real wage raises her consumption. If the share of credit-constrained agents is high enough, the positive response of aggregate consumption to the fiscal shock can be replicated. The empirical plausibility of this mechanism to generate the rise in consumption has been questioned by Coenen and Straub (2005), who report in an estimated DSGE model for the Euro Area that including credit-constrained agents is insufficient to generate the positive response of consumption due to both a small estimated share of such agents and also due to the presence of wage rigidities that mutes the effect of the falling mark-up on the real wage and hence the consumption by the credit-constrained agent.

Unlike Coenen and Straub, our computational experiments suggest that even when labor markets are frictionless, the deep habits mechanism ceases to generate a rise in the real wage necessary to overcome the negative wealth effect of government spending shocks in the presence of increasing price stickiness. Naturally, for a mechanism that relies heavily on the rise in the real wage and the intra-temporal substitution effect to generate crowding-in, the link between the mark-up and the real wage is further weakened by the presence of nominal wage stickiness. Even when price-stickiness is quite mild, increasing nominal wage rigidity by itself induces the crowding-out of consumption under deep habits.

4 Dissaggregating Real Exchange Rate Dynamics

In Chapter 4, we return to the framework synthesizing NOEM models with Bayesian estimation techniques. But instead of restricting attention to the trade balance as in Chapter 2, we focus on the second important variable of interest in international macroeconomics: the real exchange rate.

Key to understanding the real exchange rate are its multiple constituents, the nominal exchange rate as well as the domestic and international prices of goods and services. Extant empirical analyses of the nexus between the real exchange rate and its component prices have relied on a statistical decomposition of the in-sample volatility of the real exchange rate into that of its various components in reduced-form models. The evidence is mixed. Engel (1999) and Chari, Kehoe and McGrattan (2002) decompose the variance of the CPI-based US real exchange rate and report that almost none of the volatility emanates from the relative price of non-tradables to that of tradables. In contrast, Burstein, Eichenbaum and Rebelo (2006) and Betts and Kehoe (2008) find that the non-traded component account for between a third and a half of the variability of the real exchange rate.

In this essay, we employ a small open economy DSGE model, estimated over 1986-2009, to decompose the dynamic influence of domestic and international prices on the Canada-US real exchange rate, contributing simultaneously to the modern empirical general equilibrium open economy literature as well as the aforementioned reduced-form literature on the influence of relative prices on the exchange rate. Complementary to the reduced-form studies, we recover the dominant price effect, but unlike that literature, we distinguish between the movements that are generated in the domestic and the international prices and hence the aggregate real exchange rate due to the distinct structural origin of these disturbances. Specifically, we disaggregate the Canada-US real exchange rate into three relative prices (a) the international relative price of tradables (b) the relative price of imports in terms of home-produced tradables and (c) the internal relative price of non-tradables in terms of home-produced tradables. We then subject the real exchange rate to structural shocks and then observe the correspondence between aggregate real exchange rate dynamics and the dynamics of its component relative prices, in response to each disturbance.

Our results are in the direction of those reported by Engel (1999). The results indicate that a strong impetus from a disturbance specific to the non-tradable sector helps the relative price of non-tradables in terms of home-produced tradables guide the dynamic behavior of the exchange rate. However, our subsequent findings somewhat challenge the importance of the relative price of non-tradables in a broader context: the purely tradable component, *i.e.* the international relative price of tradables as well as the relative price of imports in terms of home-produced tradables, clearly generates even stronger aggregate real exchange rate dynamics for all other shocks *irrespective* of the structural origin of the disturbance. The two prime players in the forecast variance decomposition of the real exchange rate are the shock to uncovered interest parity that determines the nominal exchange rate and the mark-up shocks in the monopolistic import segment of the model, both of which generate deviations from the law of one price. The former exerts its influence mostly via the international relative price of tradables while the latter generates changes predominantly in the relative price of imports. The influence of internal tradable and non-tradable sector-specific disturbances on real exchange rate variability pales in comparison.

5 Future Research

Two remarkable economic phenomena accompanied the global recession of 2008. The first – presumably one of the symptoms of the downturn – is the collapse of international trade. Between the first quarter of 2008 and the first quarter of 2009, exports in the developed world plunged 17 percent while GDP fell 5 percent (Amiti and Weinstein 2009). The second phenomenon that has received more attention in the academic literature and the media has been the implementation of a Keynesian fiscal policy antidote to the recession. Fiscal policy-makers have resorted to massive injections of public funds to stimulate economic activity, the most prominent example being the Obama Plan in the United States.

In this section, we outline two projects that will contribute a suite of papers which are intimately related to both the aforementioned experiences: the symptom as well as the antidote. The first project extends the research agenda pursued in Chapter 2 of the dissertation and attempts to understand the sensitivity of export-flows to financial disturbances. The second project is more related to Chapter 3 and will explore the consequences of expenditure and revenue disturbances to the government budget constraint for aggregate economic activity. Both projects will address the two issues in DSGE models that are estimated with Bayesian methods on OECD data.

5.1 International Trade Flows and Finance

The trade imbalances that characterized the global economy from the early 1990s through the mid-2000s have contracted at a remarkable pace after the recent financial crises. The US trade deficit touched nearly 7 percent of US GDP in 2006 while in 2009, it more than halved to under 3 percent. Export sales are considerably riskier than domestic sales as they are prone to payment delays and defaults by foreign importers making the exporter more dependent on the financial sector for credit and hence sensitive to financial disturbances. It is likely that the crises in the banking sector led to a contraction in credit available to exporters and contributed to the collapse of international trade. Though the link between export performance and finance received little attention in the traditional literature, it has in recent times inspired a growing literature based on micro-level studies that narrowly focussed on trade-specific credit. Amiti and Weinstein (2009) and Dorsey (2009) study the link between exports and the availability of trade credit for Japan and emerging markets and report that a contraction in trade credit led to a fall in exports. Complementing these micro-level studies, this project will provide an empirical evaluation of the dynamic impact of aggregate credit shocks on trade flows in the OECD. Are exports more sensitive to shocks to the financial sector than to standard aggregate demand or supply shocks? Can the collapse of international trade be attributed to supply-side financial factors or merely a lack of aggregate demand unrelated to finance?

Gerali, Neri, Sessa and Signoretti (2009) introduce credit-supply shocks in a stylized banking sector within a closed-economy DSGE model for the Euro-Area. This is unlike the traditional set-up of Bernanke, Gertler and Gilchrist (1999) who have emphasized the demand side of the credit market. This study will introduce the mechanism from Gerali *et al* (2009) in the empirical open-economy model that is developed in Chapter 2 of this dissertation. We will then estimate the model with Bayesian methods on OECD data and generate dynamic responses from macroeconomic aggregates – with exports being the focus - in response to a contraction in credit as well as standard demand and supply shocks. What are the multiplier effects on exports after a contraction in the availability of credit? What are the relevant channels of transmission? Do exports of consumption goods react differently from the exports of durable and investment goods to financial shocks? A subsidiary issue that could be treated in a separate paper would be to compare the export dynamics implied by the DSGE model to that of an identified structural vector autoregression to understand the differential implications of a theory-based approach as the DSGE model to that of more data-driven methodologies as the vector autoregression.

5.2 The Effects of the Composition and Financing of Public Expenditure

The fiscal stimulus packages that have been implemented throughout the OECD in the wake of the recent economic downturn have revitalized the economics profession's interest in the macroeconomic impact of fiscal shocks. In the traditional business-cycle literature, public expenditure is assumed to be an unproductive residual in aggregate demand that is financed by lumpsum taxes which in turn have no impact on the economy's optimal growth path. As already mentioned in Section 3, since the typical fiscal expansion is backed by a concurrent withdrawal of resources from the private sector, it leads to a decline in other components of demand such as private consumption and investment. In contrast, a host of statistical studies that employ vector autoregressions report a positive comovement between these key macroeconomic aggregates after a rise in government spending (See Chapter 3 of this dissertation and the references cited therein).

By design, the traditional forward-looking economic models are likely to inaccurately estimate the impact of the expansion on aggregate economic activity (See for *e.g.* Cogan, Cwik, Taylor and Wieland 2009 among many others). While the revenue side of the government's budget constraint is too simplistic to influence the behaviour of the private sector, these models also do not allow for a positive impact of public expenditure shocks on other components of aggregate demand and even negates their comovement.

The second project aims to bridge this disconnect between the traditional theory and the data. It proposes to use a structural macroeconometric model to address distinct issues on the relation between economic activity and stochastic disturbances in the government's budget constraint. Firstly, we will study the expenditure side by allowing for the differential impact of public sector consumption and investment. Secondly, we will examine the effects of distortionary taxes on consumption, capital or labor income to finance the fiscal expansion. Intuitively, the efficacy of a fiscal expansion in influencing economic activity will depend on what the public sector spends on and how it finances its expenditure.

The theoretical underpinnings of the model will mainly draw from two general equilibrium studies of fiscal policy. Ambler and Paquet (1996) decompose public expenditure into those for consumption and investment. In their set-up, while public consumption is modelled as unproductive as in the traditional literature, investment by the public sector, for e.g. infrastructure, is assumed to enhance the economy's production possibility frontier. Forni, Monteforte and Sessa (2009) model a variety of disturbances on the tax revenue side. We will then embed various features of the fiscal sectors in the aforementioned studies into the empirical DSGE model of Smets and Wouters (2007), that while enjoying considerable success in terms of statistical fit, employs only the traditional rudimentary fiscal sector. We will use Bayesian methods to estimate various versions of the model on US as well as Euro-Area data. Several questions of equal interest to policy-makers as well as theorists can be addressed within the framework of the estimated model. For example, what are the contemporaneous impact- and long-run multipliers of a rise in public consumption or investment on aggregate output? Are they different from those computed from a traditional set-up with a simpler public sector? Are there differences between the US and the Euro-Area in the response of output to fiscal expansions? Does public investment lead to a decline in private investment? How does the nature of tax-financing matter?

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Chapter 2

Dissecting the Dynamics of the US Trade Balance in an Estimated Equilibrium Model

Dissecting the Dynamics of the US Trade Balance in an Estimated Equilibrium Model*

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Abstract

In an estimated two-country DSGE model, we find that investment-specific technological shocks account for more than half the forecast variance of cyclical fluctuations in the US trade balance. Both domestic investment-specific technological shocks and disturbances affecting investment dynamics in the rest of the world have a substantial impact on the variance of the imbalance. Neutral technology shocks matter much less for the variance and even lead to procyclicality in the trade balance.

JEL classification: C11, F41

Keywords: New Open Economy Macoreconomics, US Trade Balance, Investment-specific Technological Shocks, Bayesian Inference.

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*We acknowledge financial support from the Inter-University Attraction Poles Program-Belgium Science Policy (Contract Number P6/07) and the Flemish Fund for Scientific Research (FWO). This paper was in part written while the first author was visiting the National Bank of Belgium. We thank Lieven Baert, Christiane Baumeister, Mathieu Bussiére, Lilia Cavallari, Fabrice Collard, Giancarlo Corsetti, Ferre de Graeve, David de La Croix, Rafael Domenéch, Nicolas Groshenny, Freddy Heylen, Francesco Furlanetto, Mathias Hoffmann, Robert Kollmann, Vivien Lewis, Giulio Nicoletti, Pau Rabanal, Morten Ravn, Frank Smets, Arnoud Stevens, Lenno Uusküla, Ine Van Robays, Raf Wouters, participants at the Dynare Conference 2008 in Boston, ICMAIF Crete 2009, 24^{th} Congress of the European Economic Association 2009 in Barcelona and seminar participants at the National Bank of Belgium for helpful suggestions. All remaining errors are ours.

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1 Introduction

A vast literature in international macroeconomics has focused on the deterioration of the external position of the United States (US) and its consequences for the global economy.[1] This paper disentangles the stochastic influences on the US trade balance over the last three decades by estimating a two-country dynamic stochastic general equilibrium (DSGE) model with fourteen structural innovations using Bayesian methods. The model can be seen as a two-country version of the closed economy models described in Smets and Wouters (2003, 2007), where the second 'country' is a trade-weighted aggregate of sixteen OECD partners with whom the US has experienced deficits for a reasonably long span of time.

Several authors, examining different facets of the US external position using diverse methodologies, have identified a causal link between movements in US productivity and the external balance. Bussière, Fratzscher and Müller (2005) find empirical support for shifts in total factor productivity (TFP) having a significantly negative impact on the US current account. Corsetti, Dedola and Leduc (2006) report a negative association between productivity shocks in US manufacturing and US net exports while Corsetti and Konstantinou (2009) find that permanent technological shocks raise US consumption and net foreign liabilities persistently. Also in the theoretical literature, Backus, Kydland and Kehoe (1994) and Kollmann (1998) explain trade balance fluctuations on the basis of TFP shocks in calibrated two-country DSGE models.

Our results corroborate the 'productivity-view', but in a distinct way. Technological shocks influence the cyclical behavior of the trade balance strongly *only if they are specific to investment*. Across a spectrum of model specifications, we find compelling evidence that investment-specific technology shocks have a robust influence by explaining up to more than half of the forecast variance of US net exports over the cycle. Both domestic investment-specific technological shocks and disturbances affecting investment dynamics in the rest of the world (RoW) have a substantial impact on the variance of the imbalance. On the other hand, neutral technological shocks, as in TFP, have little impact on the variance. The US TFP shock even improves the trade balance in impulses due to the

[1] In 2008, the US trade deficit touched the 696 billion dollar mark and as a proportion of GDP equalled 4.82 percent (FRED II data). In this paper, we restrict the attention to the cycle of the trade balance while abstracting from the trend. Other authors, *e.g.* Engel and Rogers (2006) have examined the long-run path of the US trade balance.

strong deterioration in the US terms of trade that induces expenditure-switching in favor of US exports. We observe a relevant impact of uncovered interest parity (UIP) innovations on trade balance fluctuations, but the magnitude is much lower than in other studies (*e.g.* Bergin 2006). Furthermore, we find a limited role for domestic and foreign wage mark-up, time impatience, monetary and fiscal policy shocks, as well as purchasing power parity disturbances.

This paper lies at the interface of several strands of the literature. First, our results that underscore the importance of investment shocks for the US trade balance complements the findings of closed economy studies that emphasize the relevance of these shocks for the overall US business cycle. For instance, Justiniano, Primiceri and Tambalotti (2009a) attribute about half the conditional forecast variance of US GDP over the cycle to US investment shocks.[2] Despite the fact that we find a more modest influence of investment shocks on US output variability than Justiniano *et al.* (2009a), *i.e.* values under 30 percent at all horizons, the rise in investment that the technological disturbance evokes is strong enough to generate very significant movements in the US external position.[3]

The paper is also related to a number of macroeconometric studies that assess the driving forces of the US trade balance. Bems, Dedola and Smets (2007) find that fiscal shocks and investment-specific technological change have had a negative influence on the trade balance but they focus solely on the influence of domestic shocks in a structural vector autoregression framework. Bergin (2006) uses maximum likelihood techniques to estimate a small-scale New Keynesian model of the US and the remaining of the G-7 countries and finds that UIP shocks explain the bulk of trade balance fluctuations. We find a more suppressed role for UIP shocks as we employ other frictions, observable data series and shocks, in particular investment and corresponding disturbances.[4] The latter is not a surprise given the fact that about three quarters of US non-fuel imports and exports are capital goods and consumer durables, which contrasts with an investment

[2] Another important study is that of Fisher (2006) who presents vector autoregression evidence on the relevance of investment shocks.

[3] The main factor determining the incongruity in results for US GDP relative to Justiniano *et al.* (2009a) is that we do not include (changes in) inventories to our data series on aggregate investment primarily due to the non-availability of such data for our RoW aggregate. The role of investment-specific technology shocks for the domestic economy we find is more in line with Smets and Wouters (2007) who also do not include inventories.

[4] Importantly, Bergin (2006) also estimates the model in country differences and hence can only identify *relative* shocks. Our model is asymmetric as we allow parameters and shocks to vary across countries.

share in domestic GDP of about 20 percent, as documented by Erceg, Guerrieri and Gust (2008). Allowing for different shares of imports in consumption and investment goods in the estimations raises the influence of investment-specific technological shocks on the trade balance. When we employ the traditional specification seen in *e.g.* Backus, Kydland and Kehoe (1994), that allows imports to be dependent only on aggregate absorption, the reaction of the trade balance to investment shocks is somewhat more subdued.

Finally, we contribute to the recent tradition of New Keynesian two-country models estimated with Bayesian methods seen in Rabanal and Tuesta (2009) and Lubik and Schorfheide (2005). These authors study the dynamics of the Euro-Dollar exchange rate while we focus on the trade balance. Our model is also much less stylized and the considerably richer data-set that we employ in its empirical implementation enables the identification of a wider array of structural shocks.

We proceed as follows. The next section details the baseline theoretical model we set up. Section 3 presents the estimation results from this model. In Section 4, we carefully evaluate the robustness of the main findings by subjecting the baseline model to perturbations and examine the sources of differences relative to the existing literature. Finally, Section 5 concludes.

2 A Benchmark Two-Country Model

The baseline specification we use can be seen as a two-country version of the closed-economy models described in Smets and Wouters (2003, 2007), henceforth SW (2003, 2007). The open economy dimension deviates from the convention in only one aspect, *i.e.* the treatment of the intensity of imports in aggregate consumption and investment.[5] Erceg *et al.* (2008) note that in the data, US exports and imports are heavily concentrated towards capital goods and durables, making the consumption basket considerably less open to imports than the investment basket. Hence, following these authors, we allow for different shares of imports in each.[6] Since the two countries in the model are isomorphic, we

[5] In line with the empirical NOEM-literature, *e.g.* Rabanal and Tuesta (2009), Bergin (2006), De Walque, Smets and Wouters (2005) and Lubik and Schorfheide (2005), we impose the same values for the steady-state shares and open economy parameters across the two countries. To preserve empirical tractability, just as our precedents, we do not model a non-tradable sector.

[6] Erceg *et al.* (2008) compare this 'disaggregated' specification with the popular 'aggregated' Armington specification, which assumes the existence of a final good sector that combines domestic and imported goods

only present equilibrium conditions for the Home economy that are log-linearized around a simple symmetric non-stochastic steady-state with balanced trade and no inflation or exchange rate depreciation. Variables presented as logarithmic deviations from the steady-state are denoted by a superscript '$\widehat{\ }$'. Typically, foreign-country variables and parameters are denoted with a superscript ' * '. The innovations in all the AR(1) processes, η_t^x are *i.i.d.* $\mathcal{N}(0, \sigma_x)$ and $\rho_x \in [0, 1)\ \forall x$. We follow Bergin (2006) in abstracting from balanced growth and as in SW (2007), all the shocks in the theoretical model are normalized so that they enter the estimation with a unit coefficient. In Section 4, we discuss the robustness of the results when alternative specifications for our benchmark model are used.

Aggregation As in Erceg *et al.* (2008), an aggregation sector produces Armington aggregates of the composite Home and imported bundles for final consumption (C) and final investment (I). $Z \in \{C,\ I\}$ denotes the output of the distribution sector for *either* consumption or investment. In the Armington aggregator, Z is a combination of the domestic bundle Z_H and the imported bundle Z_F that are in turn Dixit-Stiglitz aggregates of differentiated intermediate varieties. The analogs in the foreign country are indicated by Z_F^* and Z_H^*. ξ_Z denotes the share of imports in the respective aggregator for consumption and investment. The price index of the domestic bundle (GDP deflator) is denoted by P_H in the home region and P_F^* in the foreign region. Imports at home are sold at a price P_F while the analogous price in the Foreign region is given by P_H^*. The aggregate price levels, *i.e.* the consumer price index and the investment deflator, are convex combinations of the GDP deflator and the price of imports.

$$\hat{P}_{Zt} = (1 - \xi_Z)\hat{P}_{Ht} + \xi_Z \hat{P}_{Ft} \tag{1}$$

We define $\widehat{ToT} \equiv \hat{P}_F - \hat{P}_H$ and $\widehat{ToT}^* \equiv \hat{P}_H^* - \hat{P}_F^*$ as the Home and Foreign terms of trade that determine the rate at which agents substitute the imported bundle for the domestically produced bundle. If $\mu > 0$ denotes the trade elasticity, the demand functions for the domestic bundle and imported bundle are given as

$$\hat{Z}_{Ht} = \hat{Z}_t + \mu \xi_Z \widehat{ToT}_t \tag{2}$$

$$\hat{Z}_{Ft} - \hat{Z}_{Ht} = -\mu \widehat{ToT}_t \tag{3}$$

to produce a composite good that is used for both consumption and investment, disallowing the use of different import-intensities. Backus *et al.* (1994), Raffo (2008), Bergin (2006) and De Walque, Smets and Wouters (2005) use the aggregated specification.

Intermediate Sector There exists a continuum of intermediate monopolistic firms, each of which produces a differentiated variety that can be either consumed or invested. The firm rents capital services K^S and labor N at (GDP deflator-based) real rates r^k and w and combines the factors in a Cobb-Douglas aggregate. As seen in Rabanal and Tuesta (2009), the firm sets prices in the local currency in the market of destination and exchange rate pass-through is decreasing in the degree of price stickiness. $\theta_H \in (0,1)$ and $\theta_H^* \in (0,1)$ are the Calvo probability parameters for domestic sales and exports respectively, while $\iota_P \in [0,1]$ denotes the degree of price indexation for domestic sales. If $\beta \in (0,1)$ denotes the agent's subjective discount factor and $\mathbf{E}_t$ is the expectation operator conditional on the information set at the beginning of period t, the Phillips curve for domestic sales is given by

$$\hat{\pi}_{Ht} = \frac{\iota_P}{1+\beta\iota_P}\hat{\pi}_{Ht-1} + \frac{\beta}{1+\beta\iota_P}\mathbf{E}_t\hat{\pi}_{Ht+1} + \frac{(1-\beta\theta_H)(1-\theta_H)}{\theta_H(1+\beta\iota_P)}\left[(1-\alpha)\hat{w}_t + \alpha\hat{r}_t^k - \varepsilon_t^{TFP}\right] \tag{4}$$

α is the share of capital services in the production function and exogenous TFP follows $\varepsilon_t^{TFP} = \rho_{TFP}\ \varepsilon_{t-1}^{TFP} + \eta_t^{TFP}$. As we do not fit export-import price series in the baseline estimations, we keep the export pricing equations simple by abstracting from indexation. The assumption of local currency pricing implies that the real exchange rates RER^Z and the terms of trade enter the Phillips curves for export sales.[7]

$$\hat{\pi}_{Ht}^* = \beta\mathbf{E}_t\hat{\pi}_{Ht+1}^* + \frac{(1-\beta\theta_H^*)(1-\theta_H^*)}{\theta_H^*}\begin{bmatrix} (1-\alpha)\hat{w}_t + \alpha\hat{r}_t^k - \varepsilon_t^{TFP} \\ -\widehat{RER}_t^Z - \xi_Z\widehat{ToT}_t - (1-\xi_Z)\widehat{ToT}_t^* \end{bmatrix} \tag{5}$$

Real Exchange Rate A rise in the nominal exchange rate denoted by NER implies a depreciation of the Home currency. We use the nominal depreciation of the US dollar as an observed variable in our estimations and follow Lubik and Schorfheide (2005) in allowing for an *i.i.d.* disturbance η^{PPP} to enter the definition of the real exchange rate. This shock captures deviations from purchasing power parity not accounted for by endogenous frictions such as local currency pricing and home-bias in trade and hence will help the model fit the exchange rate series better.[8]

$$\widehat{RER}_t^Z - \widehat{RER}_{t-1}^Z = \left(\widehat{NER}_t - \widehat{NER}_{t-1}\right) + \hat{\pi}_{Zt}^* - \hat{\pi}_{Zt} + \eta_t^{PPP} \tag{6}$$

[7] The indexation of the real exchange rate and the share of imports by Z, implies that the nominal exchange rate can be expressed in terms of the CPI-based as well as the investment deflator-based real exchange rates.

[8] In one of our robustness checks, we remove this disturbance.

Consumption and Investment Consumers have access to domestic and foreign currency denominated private risk-free bonds as well as the domestic capital stock to facilitate the inter-temporal transfer of wealth. Optimization yields three asset-pricing conditions.

$$\hat{C}_t = \frac{1}{1+\vartheta}\mathbf{E}_t\hat{C}_{t+1} + \frac{\vartheta}{1+\vartheta}\hat{C}_{t-1} - \frac{1}{\sigma_C}\frac{(1-\vartheta)}{(1+\vartheta)}\left(\hat{R}_t - \mathbf{E}_t\hat{\pi}_{Ct+1}\right) + \varepsilon_t^{TI} \tag{7}$$

$$\mathbf{E}_t\widehat{NER}_{t+1} - \widehat{NER}_t = \hat{R}_t - \left(\hat{R}_t^* - \kappa\widehat{NFA}_{t+1} + \varepsilon_t^{UIP}\right) \tag{8}$$

$$\widehat{TQ}_t = (1-\beta(1-\delta))\,\mathbf{E}_t\hat{r}_{t+1}^k + \beta(1-\delta)\,\mathbf{E}_t\widehat{TQ}_{t+1} - \left(\hat{R}_t - \mathbf{E}_t\hat{\pi}_{Ct+1}\right) \tag{9}$$

Equation 7 determines the flow of aggregate consumption. The curvature parameter $\sigma_C > 0$ and the external habit coefficient $\vartheta \in [0,1)$ govern the inter-temporal elasticity of substitution. R is the gross interest rate on domestic bonds set by the monetary authority while π_C is the gross inflation in the consumer price index. ε^{TI} is a disturbance that can be interpreted as a 'time-impatience' shock to the subjective discount factor and evolves as $\varepsilon_t^{TI} = \rho_{TI}\,\varepsilon_{t-1}^{TI} + \eta_t^{TI}$. Equation 8 presents uncovered interest parity (UIP), the arbitrage condition for home and foreign bonds. Since the failure of UIP in its primitive form has been well documented, we add to this condition a stochastic term ε^{UIP} whose evolution obeys $\varepsilon_t^{UIP} = \rho_{UIP}\,\varepsilon_{t-1}^{UIP} + \eta_t^{UIP}$. The additional cost of acquiring net foreign assets NFA measured by $\kappa > 0$ acts as a stationarity-inducing device.[9] The third asset-pricing condition Equation 9 determines the behavior of Tobin's Q.

Two key relationships that influence the dynamics of aggregate investment and the physical capital stock $\left(\bar{K}\right)$ are

$$\hat{I}_t = \frac{\beta}{1+\beta}\mathbf{E}_t\hat{I}_{t+1} + \frac{1}{1+\beta}\hat{I}_{t-1} + \frac{1}{\psi(1+\beta)}\left(\widehat{TQ}_t - \xi_I\widehat{ToT}_t\right) + \varepsilon_t^{INV} \tag{10}$$

$$\hat{\bar{K}}_t = \delta\hat{I}_t + (1-\delta)\,\hat{\bar{K}}_{t-1} + \delta\psi(1+\beta)\,\varepsilon_t^{INV} \tag{11}$$

The presence of the investment adjustment cost parameter $\psi > 0$ delays the response of aggregate investment to changes in Tobin's Q and its relative price.[10] ε^{INV} is an

[9] See Bergin (2006) and the references therein for details of the non-stationarity problem in incomplete market models.

[10] Unlike SW (2003, 2007), the terms of trade affect the investment equation as imports enter the investment basket and the price of aggregate investment is deflated by the GDP deflator. Alternatively, if nominal investment is deflated by the CPI, then the relative price would be given as $(\xi_I - \xi_C)\,\widehat{ToT}$.

investment-specific technology shifter that stimulates the conversion of investment into the capital stock, that reflects in part, in a fall in the price of newly-installed capital.

Very recently, Justiniano, Primiceri and Tambalotti (2009b) debates the interpretation of the investment disturbance as a purely technological one by relating it too tightly to the relative price of investment goods. More specifically, they estimate a closed-economy model of the US positioning two disturbances that stimulate investment in distinct ways. The first indicates improvements in technology that affect the transformation of consumption goods into investment goods in a perfectly competitive investment goods sector. Consequently, the relative price of investment perfectly (negatively) covaries with this technological shock. The second is a disturbance that accelerates the conversion of savings into the capital stock and is termed a marginal efficiency of investment shock. The latter shock is found to be very important for US GDP over the business cycle while the technology shock that is strictly associated with the relative price of investment plays virtually no role. In our set-up, we do not distinguish between the two fundamental disturbances modelled in Justiniano *et al.* (2009b) and the investment shock in Equation 10 or the models of SW (2003, 2007) is a reduced-form combination of these two shocks. Interestingly, the macroeconomic dynamics triggered by the shock in Equation 10 makes it observationally equivalent to the shock to the marginal efficiency of investment modelled by Justiniano *et al.* (2009b). As their estimate of the marginal efficiency shock correlates strongly with available measures of interest rate spreads, Justiniano *et al.* conclude that the marginal efficiency disturbance may proxy shocks to the functioning of the (unmodelled) financial sector. While we do not challenge this claim, we opt for the traditional classification in the literature and interpret the efficiency shock as 'investment-specific technology'. Within our model environment, the shock also induces a fall in the price of newly-installed capital, albeit not on a one-to-one basis as in the case of the purely technological disturbance affecting the separately-modelled investment goods sector seen in Justiniano *et al.* (2009b). This property of the shock in the investment equation allows us to distinguish it clearly from the traditional neutral technology shock that leads to a fall in the price of *all* goods. We will henceforth refer to the investment disturbance as simply the *investment shock* and it evolves as $\varepsilon_t^{INV} = \rho_{INV}\ \varepsilon_{t-1}^{INV} + \eta_t^{INV}$.

The capital services that enter the firm's production function depend on the lagged physical capital stock and the degree of capacity utilization that is a function of the rental rate of capital. $\varphi \in [0,1]$ governs the strength of capacity utilization.

$$\hat{K}_t^S = \hat{\bar{K}}_{t-1} + \frac{1-\varphi}{\varphi}\hat{r}_t^k \tag{12}$$

On the other hand, the return on capital is determined by

$$\hat{r}_t^k + \hat{K}_t^S = \hat{w}_t + \hat{N}_t \tag{13}$$

The wages are set as in SW (2003). The agent provides a differentiated labor service in the factor market and has monopoly power. If $\theta_W \in (0,1)$ is the Calvo parameter for nominal wage stickiness, $\sigma_N \geqslant 0$ is the reciprocal of the Frisch elasticity of labor and $\chi_W > 1$ is the elasticity of substitution between labor varieties in the Dixit-Stiglitz aggregate, the wage equation is given by

$$\begin{aligned}\hat{w}_t \;=\; & \frac{\beta}{1+\beta}\mathbf{E}_t\hat{w}_{t+1} + \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\beta}{1+\beta}\mathbf{E}_t\hat{\pi}_{Ht+1} - \frac{1+\iota_W\beta}{1+\beta}\hat{\pi}_{Ht} + \frac{\iota_W}{1+\beta}\hat{\pi}_{Ht-1} \\ & -\frac{(1-\beta\theta_W)(1-\theta_W)}{\theta_W(1+\sigma_N\chi_W)(1+\beta)}\left[\hat{w}_t - \sigma_N\hat{N}_t - \sigma_C\frac{\hat{C}_t - \vartheta\hat{C}_{t-1}}{1-\vartheta} - \xi_C\widehat{ToT}_t\right] + \varepsilon_t^{WM}\end{aligned} \tag{14}$$

$\iota_W \in [0,1]$ is the degree of indexation of wages to lagged inflation in the GDP deflator and ε^{WM} is a cost-push disturbance that can be interpreted as a shock to the mark-up of the real wage over the marginal rate of substitution between consumption and leisure (in square brackets) and follows an ARMA $(1,1)$ process defined as $\varepsilon_t^{WM} = \rho_{WM}\,\varepsilon_{t-1}^{WM} + \eta_t^{WM} - \nu_{WM}\,\eta_{t-1}^{WM}$ such that $\nu_{WM} \in [0,1)$.

Government Spending and Goods Market Clearing Government spending is financed by lump-sum taxes and falls exclusively on the domestic bundle.[11] We follow the convention in the literature by reducing government spending to a residual shock in aggregate demand that follows $\varepsilon_t^{GOV} = \rho_{GOV}\,\varepsilon_{t-1}^{GOV} + \eta_t^{GOV}$.

Equation 15 represents the goods market clearing condition. Output is absorbed by domestic sales for consumption and investment at home, exports, domestic government

[11] Our decision to abstract from public debt is motivated by the fact that the purely Ricardian agents reduce their current expenditures when there is a rise in government spending, precluding a strong negative impact on the trade balance. The assumption of a balanced budget implies that this paper does not provide an empirical evaluation of the Twin Deficits hypothesis. This view suggests that the deterioration of the trade balance is determined by the lack of saving by the Federal government. See Corsetti and Müller (2006) and the references therein for more details.

spending and the cost of capacity utilization. Ξ_C and Ξ_I indicate the steady-state shares of consumption and investment in output.

$$\hat{Y}_{Ht} = \Xi_C \left(1-\xi_C\right)\hat{C}_{Ht} + \Xi_I \left(1-\xi_I\right)\hat{I}_{Ht} + \xi_C \Xi_C \hat{C}^*_{Ht} + \xi_I \Xi_I \hat{I}^*_{Ht} + \varepsilon_t^{GOV} + \frac{\bar{K}\bar{r}^k}{\bar{Y}_H}\frac{1-\varphi}{\varphi}\hat{r}_t^k \quad (15)$$

Balance of Payments The inter-temporal flow of net foreign assets is given by

$$\begin{aligned}\widehat{NFA}_t - \frac{1}{\beta}\widehat{NFA}_{t-1} &= \Xi_C \xi_C \left[\hat{C}^*_t - \hat{C}_t + \widehat{RER}_t^C + (\mu-1)(1-\xi_C)\left(\widehat{ToT}_t - \widehat{ToT}_t^*\right)\right] \\ &+ \Xi_I \xi_I \left[\hat{I}^*_t - \hat{I}_t + \widehat{RER}_t^I + (\mu-1)(1-\xi_I)\left(\widehat{ToT}_t - \widehat{ToT}_t^*\right)\right]\end{aligned} \quad (16)$$

The aggregate net exports to GDP ratio of the Home economy is given by the right hand side of Equation 16 and we will henceforth refer to it simply as the trade balance. It is expressed as the sum of net exports for consumption and net exports for investment weighted by their respective shares of imports and steady-state shares in output. A decomposition of the trade balance into the sum of volumes for consumption and investment net exports, the real exchange rates and the differential in the terms of trade should aid our analysis of the impact of the various structural shocks on each of these components.[12] Specifically, the trade balance can also be redefined as

$$\begin{aligned}\widehat{RTB}_t &= \overbrace{\Xi_C \xi_C \left(\hat{C}^*_t - \hat{C}_t\right)}^{\widehat{C}_t^{VOL}} + \overbrace{\Xi_I \xi_I \left(\hat{I}^*_t - \hat{I}_t\right)}^{\widehat{I}_t^{VOL}} + \overbrace{\Xi_C \xi_C \widehat{RER}_t^C + + \Xi_I \xi_I \widehat{RER}_t^I}^{\widehat{RER}_t} \\ &+ \underbrace{(\mu-1)\left[\Xi_C \xi_C (1-\xi_C) + \Xi_I \xi_I (1-\xi_I)\right]\left(\widehat{ToT}_t - \widehat{ToT}_t^*\right)}_{\widehat{RToT}_t}\end{aligned} \quad (17)$$

Monetary Policy The model is closed with the monetary authority following a simple empirical Taylor-type rule to set the nominal interest rate, targeting inflation in the GDP deflator and the level as well as changes in output, and is subject to exogenous monetary policy disturbances:

$$\hat{R}_t = \rho_{MON}\,\hat{R}_{t-1} + (1-\rho_{MON})\left(\phi_\pi \hat{\pi}_{Ht} + \phi_y \hat{Y}_{Ht}\right) + \phi_{\Delta y}\left(\hat{Y}_{Ht} - \hat{Y}_{Ht-1}\right) + \eta_t^{MON} \quad (18)$$

[12] Raffo (2008) analyzes net exports fluctuations across OECD countries using a similar quantity-versus-relative price decomposition of the trade balance.

3 Estimation

3.1 Data and Estimation Method

The empirical treatment of the foreign region in the model, the RoW, poses a significant challenge. Long macroeconomic time series are unavailable for high-saving emerging economies, for instance East Asian countries, that have centered in recent debates in the context of the US deficit. This impedes our effort to disentangle the effect of external disturbances on the imbalance. To remedy the lack of data to form the RoW aggregate, we propose an alternative strategy. Panel (a) of Figure 1, displays the savings and investment patterns in the US and an aggregate of sixteen industrialized economies - Canada, Japan, Korea, the UK and twelve economies from the Eurozone - for the period 1980-2005. Clearly, a savings-investment imbalance, which necessarily mirrors a trade imbalance, has always prevailed even within the industrialized countries, worsening after the early nineties. This feature of the data motivates our decision to use the bilateral trade balance between the US and this group of OECD economies, which at least in part reflects the observed savings-investment disequilibrium, as a proxy for the actual US trade balance in the estimations. In a robustness check, we also employ the actual trade balance in the estimations and obtain strikingly similar results (see Section 4). Panels (b) and (c) of Figure 1 compare the constructed intra-OECD trade balance to US GDP series with the actual series, in levels and after linearly detrending respectively. The OECD series tracks the actual rather well until the late 1990s before the omitted economies started to play a dominant role. As can be seen in Table 1, the two series are highly correlated, both in levels and after detrending. Towards the later years of the sample, the disparity between the two series increases even though they continue to display the high cross-correlation, which is what really matters if we want to analyze the cycle of the balance. Time series from the OECD trade-partners are aggregated using time-varying trade-shares to embody the RoW in the empirical analysis.[13]

To identify the fourteen structural innovations in the theoretical model - η^{TI}, η^{TI*}, η^{INV}, η^{INV*}, η^{TFP}, η^{TFP*}, η^{WM}, η^{WM*}, η^{GOV}, η^{GOV*}, η^{UIP}, η^{MON}, η^{MON*} and η^{PPP}- an equal number of macroeconomic time series are matched with their analogs in the model. We use US and RoW series on real consumption, real investment, real GDP, real wage

[13] Bergin (2006), Corsetti *et al.* (2006) and Bussière *et al.* (2005) are other studies that use multi-country data aggregates in empirical models of the US external balance.

inflation, GDP deflator inflation and the nominal interest rates along with the net exports to US GDP ratio and the nominal exchange rate spanning 1980Q1-2005Q4. The data series on the trade balance is linearly detrended while the interest rates, price inflation and wage inflation series are demeaned. All other series enter the estimation in demeaned first-differences. Table 1 also provides the unconditional moments of the data and the model analog for each (US) series that we employ. Other particulars about the data are detailed in the Appendix.

We apply the Bayesian estimation methodology of SW (2003, 2007) and we refer to the original papers for a detailed description. In a nutshell, the Bayesian paradigm facilitates the combination of prior knowledge about structural parameters with information in the data as embodied by the likelihood function. The blend of the prior and the likelihood function yields the posterior distribution for the structural parameters which is then used for inference. The appendix also provides further technical details on the estimation methodology.

3.2 Priors

An overview of our priors can be found in Table 2. The prior distributions given to the estimated structural parameters are quite diffuse and comparable to those used in other studies. The parameters that are not estimated are given dogmatic priors at calibrated values. We follow the strategy of Bergin (2006) and Rabanal and Tuesta (2009) in *fixing,* rather than estimating, the import-shares.[14] We allow for different import-intensities for consumption and investment by computing the means of the shares of imports from annual data over 1980-2005 from the Bureau of Economic Analysis.[15] We set the import-share for consumption ξ_C at 0.039 and the investment analog ξ_I at 0.419.[16] These values are quite

[14] As we will see in Section 4.2 on robustness checks, estimating this critical parameter can drive it to unrealistic values.

[15] In particular, we refer to Table 2b (U.S. Trade in Goods) from U.S. International Transactions Accounts Data from the BEA website. We define Investment Imports $\equiv$ Industrial supplies and materials + Capital goods, except automotive + Automotive vehicles, parts, and engines and Consumption Imports $\equiv$ Consumer goods (nonfood), except automotive + Foods, feeds, and beverages. The import-shares are computed by dividing these by aggregate investment and consumption.

[16] The weights that consumption and investment receive in the definition of the trade balance to output ratio are not as disparate as these import-intensities might suggest, because consumption is by far the most dominant component of output. Specifically, in Equation (17), the weights given to consumption and investment net exports are given by $\Xi_C \xi_C = 0.0238$ and $\Xi_I \xi_I = 0.088$.

similar to those used by Erceg *et al.* (2008) in their simulations. Other calibrations are very standard in the literature, *e.g.* SW (2007). These priors remain unaltered through all our estimations unless specifically mentioned otherwise.

3.3 Baseline Results

3.3.1 Posterior Estimates

The medians and standard deviations of the posterior distributions of the structural parameters are also reported in Table 2. The estimates of the US parameters are in the ballpark of those obtained in SW (2007). The RoW analogs are of comparable magnitudes except for the habit coefficient and price Calvo parameters, which are rather low at 0.08 and 0.14 respectively. The trade elasticity is somewhat on the higher side at about 1.9 which exceeds the estimates of Rabanal and Tuesta (2009), Bergin (2006) and Lubik and Schorfheide (2005), but is below the calibrated value of 2 used in Erceg *et al.* (2008). Most shocks display relatively high persistence. An important exception is the UIP shock whose AR(1) coefficient is estimated at about 0.85, which is significantly lower than the values ranging between 0.92 and 0.98 reported by Bergin (2006) and De Walque *et al.* (2005).

3.3.2 Impulse Response Analysis

In Figure 2, we present the responses of the main components of the trade balance - the impact on the relative volumes of net exports as well as the real exchange rate and the differential in the terms of trade - to various structural shocks. In our discussion, we focus on the impact of US shocks on US variables, as the responses induced by the RoW analogs are symmetric with only minor differences in magnitudes.[17]

Neutral (TFP) and Investment-specific Technology Shocks On the domestic front, not shown in the figures, the responses to both shocks are in line with the existing literature (*e.g.* SW 2007). A rise in US TFP draws positive responses from consumption, investment and total GDP as the permanent income of the agents rise. It results in a deterioration of the US terms of trade and a strong real depreciation of the dollar which is

[17] All results are available upon request.

driven by a fall in domestic inflation and interest rate. The rise in consumption leads to a small but significant decline in the net export volume of consumption goods. On the other hand, investment net export volumes do not react significantly on impact, but worsens more than the consumption-analog in the medium- and long-run. The deterioration of the US terms of trade induces a strong expenditure-switching effect in the RoW in favor of US goods. This positive relative price effect dominates the negative volume effect. The trade balance improves on impact and remains positive for about 5 years, before the effect of the terms of trade weakens and the fall in the volumes begins to dominate.

An investment-specific technology shock increases the marginal efficiency of the conversion of the investment good into the capital stock. Investment demand strongly rises on impact without a commensurate increase in output. Whereas the response of consumption is insignificant on impact, the wealth effect that typically follows a technology shock raises consumption persistently after a year. Despite the rise in domestic investment demand, the US relative terms of trade slowly *deteriorates* (see Figure 2). This apparently anomalous response of the terms of trade has been examined by Basu and Thoenissen (2008) who explore the consequences of an investment shock in a theoretical two-country model where import-intensities differ across consumption and investment. Observe that the investment shock raises the relative demand for both US and imported intermediate goods, as compared to consumption, raising the relative price of investment in terms of consumption. When the final investment good is more open to imports than the final consumption good, the domestic terms of trade has to deteriorate.[18] On impact, both consumption and investment fall slightly in the RoW while RoW output rises to feed the US investment boom. In effect, net exports decline strongly in terms of investment volumes while the fall in the consumption analog is very mild. The overall impact on the trade balance is a strong deterioration. In quantitative terms, the overall impact of a typical investment shock on the trade balance is about double of that of the neutral TFP shock.

The impact multipliers (not exhibited) of both technological shocks on US output are similar. Both shocks deteriorate the domestic terms of trade and induce expenditure-

[18] Algebraically, the relative price of investment in terms of consumption is given as $(\xi_I - \xi_C)\widehat{ToT}$ and when investment is more open to imports than consumption so that $\xi_I > \xi_C$, a rise in the relative price of investment will raise, *i.e.* deteriorate the terms of trade. This was confirmed numerically by a counterfactual experiment that used extreme home-bias in investment by setting $\xi_C = 0.15$ and $\xi_I = 0.01$, while other parameters are set at their values at the posterior median of the baseline estimation. In this scenario, the domestic terms of trade appreciate on impact after the investment shock.

switching in favor of US exports. What then explains their distinct effects on the trade balance? The crux of the differential impact lies in the ability of the investment shock to elicit a strong response from the relative *volumes*. Even though the neutral shock raises domestic absorption, the reactions from the net export volumes are very weak and the overall influence on the trade balance is determined by the positive expenditure-switching effect induced by the fall in the price of US goods. This effect even makes the trade balance behave procyclically in the short- and medium-run. The procyclicality of the trade balance runs against the received wisdom in the literature, *e.g.* Backus *et al.* (1994), Kollmann (1998), Raffo (2008) and Coeurdacier, Kollmann and Martin (2010), that emphasizes its counter-cyclical nature. In contrast, the rise in US investment induced by the investment shock leads to a fall in net traded volumes that is robust enough to dominate the positive expenditure-switching effect, generating a decline in the trade balance. The dominance of the investment shock is not a surprise. As documented by Erceg *et al.* (2008), US exports and imports are heavily concentrated in capital goods and consumer durables. Hence, a domestic or foreign shock that raises investment has a much larger effect on the US trade balance than a shock that boosts consumption with a similar magnitude, a mechanism which actually holds for all kind of shocks. Whereas the impact of both technology shocks on total output is of a similar magnitude, investment-specific technology shocks have a more powerful positive impact on US investment. As a consequence, there is a substantial fall in relative investment net export volumes which strongly deteriorates the overall trade balance. The counter-cyclical trade balance dynamics triggered by the investment shock makes it actually more appealing than the neutral shock as a stochastic driver of trade deficits.

Time Impatience, Government Spending, Monetary Policy and Wage Mark-up Shocks A time impatience shock increases consumption and output on impact while crowding-out investment. The strong demand for the domestic good results in a rise of GDP deflator inflation improving the US terms of trade. In unison with a hike in the interest rate by the monetary authority, the improved terms of trade reflect in a real appreciation of the US dollar. The net export in consumption goods declines sharply in volume terms while the response of investment volumes is insignificant. Unlike the technology shocks described above, the time-impatience shock pushes relative prices and the volumes in the same direction, and the trade balance deteriorates.

A rise in government consumption is financed by lump-sum taxes and exerts a negative wealth effect on the agents, consequently crowding-out private expenditures on consumption and investment. As the government purchases only the domestic good, inflation in the GDP deflator rises and improves the US terms of trade and along with the rise in the US interest rate, trigger an appreciation of the dollar. The higher relative price of the US good raises inflation in the RoW and the ensuing rise in the RoW interest rate has a negative impact on investment. Coupled with the fact that RoW investment is also very open to US exports and hence sensitive to its relative price, RoW investment falls. This fall is stronger than that in US investment which declines only due to the crowding-out effect of the fiscal expansion. In effect, investment net export volumes fall very mildly while consumption net export volumes improve. The investment volume effect is complemented by the stronger negative expenditure-switching effect triggered by the appreciation in the US terms of trade and the dollar. Consequently, the US trade balance worsens.

Contractionary monetary policy leads to a decrease in US investment, consumption, output and inflation. The dollar appreciates via the interest parity condition making imports cheaper and improving the US terms of trade. The latter dominates a favorable volume effect of consumption and investment, deteriorating the trade balance.

Finally, a rise in the real wage increases domestic inflation and the ensuing hike in the interest rate by the monetary authority has a negative impact on consumption and investment while appreciating the dollar. Consumption net export volumes improve mildly whereas investment volumes slightly decline due to the strong downward response of RoW investment to the appreciated US terms of trade. The decline in the trade balance is determined mostly by this negative relative price effect rather than the volumes.

UIP and Purchasing Power Parity Shocks The impact of both open economy disturbances on the main components of the trade balance are presented in the last two rows of Figure 2. A UIP shock, which can be interpreted as a rise in the risk premium on foreign borrowing, depreciates the US dollar, raises the US interest rate and lowers the RoW interest rate. This reduces US consumption and investment while increasing the RoW analogs. The volumes of net exports for both consumption and investment increase and are reinforced by positive movements in the exchange rate and the terms of trade. In effect, the US trade balance improves significantly. On the other hand, the impact of the purchasing power parity shock is statistically insignificant for all variables except for the

US dollar that experiences a strong nominal appreciation.

3.3.3 Determinants of Trade Balance Fluctuations

To evaluate the relative contributions of each of the fourteen shocks embedded in the model, Table 3 shows the variance of the forecast errors of the trade balance for several horizons. For all shocks, we report the mean of the distribution of variance decompositions based on the posterior. For comparison, the table also reports the forecast errors of some key US macroeconomic variables, *i.e.* real GDP, consumption and investment.

The relative contributions of the shocks to fluctuations in real GDP, consumption and investment are very similar to closed economy studies of the US, for instance SW (2007). As we will explain below, we find a lower contribution of investment shocks to domestic fluctuations than Justiniano *et al.* (2009). Of special interest however is the role of foreign and open economy shocks for the US business cycle. Overall, these shocks seem not to explain a lot: the total contemporaneous contribution to US GDP variability is slightly above 6 percent, which reduces to values between 4 and 5 percent in the long-run. About half of this contribution is driven by disturbances to investment in the RoW. The role for explaining US investment volatility is more relevant, *i.e.* around 20 percent in the long-run. On the other hand, when we consider trade balance fluctuations, foreign and open economy shocks turn out to be very important. In particular, they explain more than half of US trade balance variability at very short horizons and still approximately 45 percent after 40 quarters. Hence, focusing solely on the influence of domestic shocks to study the deterioration of the US trade balance (*e.g.* Bems *et al.* 2007), ignores an important source of volatility. In the remaining of this subsection, we further examine the relative contributions of the identified innovations to the variability of the trade balance.

The combined contemporaneous contribution of US and RoW monetary policy shocks to trade balance fluctuations is around 16 percent. However, at medium- and long-term horizons, the role of monetary policy shocks becomes negligible. Cost-push shocks from wages contribute very little on impact but together make up about 10 percent in the long run. The government spending shocks play a negligible role: the mean contribution of the US shock barely comes to 4 percent at all horizons. As mentioned in the previous subsection, the weak influence of government spending is due to the two opposing effects it generates on the trade balance: the negative impact originating from the net exports volumes for investment and the appreciation of the relative terms of trade and the positive influence of the fall in consumption that is crowded out. The preference shocks that capture the time impatience effect on consumption contribute very little due to two main reasons. On one hand, the import-intensity of aggregate consumption is rather low and on the other, the crowding-out effect on investment generates a positive impact on the trade balance, opposing the negative impact of rising consumption. The time impatience shocks contribute less than 3 percent at all horizons. Not surprising, given the insignificant impulse responses, purchasing power parity shocks do not contribute to trade balance fluctuations.

Unlike Bergin (2006), who finds that the UIP shock determines about two-thirds of short-run variations in the external balance (current account), we find that this shock has a modest influence. The contribution comes to about 22 percent on impact and its role decreases over time to about 15 percent over the very long run. As we will demonstrate in Section 4, one important reason for the different results, is the absence of investment shocks in his analysis.

Overall, the US trade balance is mainly driven by the US investment shock whose contemporaneous contribution is approximately 24 percent, a number which increases to 36 percent over longer horizons. The RoW analog also contributes significantly to the variance at about 20 percent at all horizons. The scenario is quite different as regards neutral technology shocks. The contribution of the US TFP shock increases from 4 percent on impact to about 10 percent in the long-run while the influence of the RoW TFP shock is much weaker at about 2 percent at most horizons. The overwhelming impact of investment shocks on the trade balance is intriguing as we observe a more even distribution of the variance contributions for US GDP, with the domestic investment, neutral TFP, wage-mark-up, government spending and monetary policy shocks all contributing substantively depending on the forecast horizon. As explained in Section 3.3.2, the dominance for explaining trade balance variability originates from a substantial relative volume effect of traded investment goods following an investment shock, which is relatively mild for all other shocks.

Our results that underscore the importance of investment shocks for the US trade balance, complements the findings of a closed economy study by Justiniano *et al.* (2009a) that emphasizes the relevance of these shocks for the US business cycle. They attribute about half the conditional forecast variance of US GDP growth over the cycle to the US investment shock. In contrast, in our case the observed first-differenced US output series is less affected by investment shocks at between 15 and 18 percent at all horizons (not exhibited). As can be seen in Table 3, our estimates are more in line with SW (2007), implying a more modest influence of the investment shock on the level of output variability at about 20 percent on impact to about 30 percent in the very long run.[19] While the treatment of the investment shock in our theoretical model is identical to that of Justiniano *et al.* (2009a), our approach deviates from theirs along several important dimensions, for instance in the openness of the economy, choice of shocks, observables, data transformations and sample period. However, the main factor determining the incongruity in results for US GDP is that we do not include (changes in) inventories to our data series on aggregate investment.[20] The difference in the data definition clearly leads to some disparity in key parameter estimates as we find a much smaller innovation to the investment shock and a higher estimate of the investment adjustment cost parameter that restrains the response of investment to structural shocks.[21] However, despite the relatively higher inertia in investment and the lower variance of the shock, the rise in investment that the technological disturbance evokes is strong enough to generate significant movements in the US external position.

4 Robustness Analysis

We now assess the robustness of our results by adding or removing elements from the baseline model. We first examine how the variance decomposition of the trade balance is sensitive to changes in the trade balance series, sample period and baseline model assumptions. We then evaluate the consequences of more fundamental alterations to the model, in particular the choice of structural shocks. Such an analysis should also allow us

[19] Justiniano *et al.* report the share of the variance of the level of output explained by investment shocks using a spectral decomposition at business-cycle frequencies and hence we cannot strictly compare our decomposition in the time domain for the level with theirs. On the other hand, SW (2007) report the variance decomposition for the level of output, just as in our case.

[20] This is primarily due to the non-availability of such data for the whole sample-period for the Euro-Area that constitutes a significant proportion of our RoW aggregate.

[21] Justiniano *et al.* (2009a) compare their results to those of SW (2007) and note the increased impact of investment shocks on US GDP when inventories are included in the investment series. To confirm, we estimated a version of our model by adding inventory data to the US series on investment, without changing the RoW series. About half of the conditional volatility of both US output and the trade balance is driven by the US investment shock in this scenario.

to compare our results with the existing literature. The results are summarized in Tables 4 and 5, which report the variance decompositions at a 4 quarter forecast horizon for the trade balance. Table 6 compares the parameter estimates obtained in the robustness checks with the baseline case.

4.1 Sensitivity of Results Retaining Baseline Shocks

Since there is the important qualification that our dataset excludes the East Asian trade partners, we estimated the baseline model with the actual series on the US trade balance as a first robustness check. As can be seen from Table 4, the relative contributions to trade balance volatility hardly change. The reason is that even though the actual trade balance is more than twice as volatile as the OECD aggregate, the correlation between the two series is very high at almost 0.8. We also re-estimated the model for 1980-2000, the period during which the OECD aggregate mimics the actual series remarkably well. Results are still in favor of investment shocks.

Investment shocks continue to dominate when we assume complete markets, *i.e.* that there exist internationally traded state-contingent bonds that insure against consumption risk for agents in both regions and the CPI-based real exchange rate is strictly tied down to relative habit-adjusted consumption (see fourth column of Table 4).[22]

$$\begin{aligned}\widehat{RER}_t^C &= \left(\frac{\sigma_C}{1-\vartheta}\hat{C}_t - \frac{\sigma_C \vartheta}{1-\vartheta}\hat{C}_{t-1}\right) - \left(\frac{\sigma_C^*}{1-\vartheta^*}\hat{C}_t^* - \frac{\sigma_C^* \vartheta^*}{1-\vartheta^*}\hat{C}_{t-1}^*\right) \\ &\quad - \left(\frac{\sigma_C\left(1+\vartheta\right)}{\left(1-\rho_{TI}\right)\left(1-\vartheta\right)}\varepsilon_t^{TI} - \frac{\sigma_C^*\left(1+\vartheta^*\right)}{\left(1-\rho_{TI}^*\right)\left(1-\vartheta^*\right)}\varepsilon_t^{TI^*}\right) \qquad (19)\end{aligned}$$

Our results are also not sensitive when we differentiate between short-run and long-run trade elasticities. For this purpose, we need to assume that the aggregation sector incurs import adjustment costs, so that the import demand function in Equation 3 becomes dynamic.[23] For $Z \in \{C,\ I\}$,

$$\hat{Z}_{Ft} - \hat{Z}_{Ht} = \frac{-\mu}{1+\Omega+\beta\Omega}\widehat{ToT}_t + \frac{\Omega\left(\hat{Z}_{Ft-1} - \hat{Z}_{Ht-1}\right) + \beta\Omega\mathbf{E}_t\left(\hat{Z}_{Ft+1} - \hat{Z}_{Ht+1}\right)}{1+\Omega+\beta\Omega} \qquad (20)$$

[22] Simultaneously, we remove net foreign assets from the model while retaining the definition of the trade balance.

[23] The import adjustment cost function is similar to that of Erceg *et al.* (2008), but unlike them, we assume that the cost is internal to the agent so that the volumes in the import equation are both forward- and backward-looking as in De Walque *et al.* (2005).

Unlike in the baseline model, the presence of adjustment cost parameter $\Omega > 0$ lowers the short-run trade elasticity and hence amplifies the response of the relative prices to structural shocks. Clearly, as shown in the fifth column of Table 4, investment shocks retain their strong influence.

As another robustness check, we used the traditional aggregation set-up as seen in Backus *et al.* (1994), henceforth BKK, so that the share of imports in the aggregation sector is specified in terms of total absorption. Due to its simplicity, the BKK specification has been popular in the empirical literature, *e.g.* Rabanal and Tuesta (2009), Bergin (2006) and De Walque *et al.* (2005). The trade balance is now given as

$$\widehat{RTB}_t = \xi \left(\hat{Y}_t^* - \hat{Y}_t \right) + \xi \widehat{RER_t} + (\mu - 1)\, \xi \, (1 - \xi) \left(\widehat{ToT}_t - \widehat{ToT_t}^* \right) \tag{21}$$

The import share of aggregate absorption ξ is fixed at 0.15 in the estimation as in BKK (1994).[24] At the 4 quarter horizon, exhibited in the last column of Table 4, the home and foreign investment shocks still dominate albeit their joint contribution is slightly lower than in the baseline model, *i.e.* a reduction from 58 percent to 49 percent.

Investment shocks also dominate in other estimated versions of the baseline model that are not presented here, but available upon request: (a) using the sample means of the trade-shares to aggregate RoW time series (b) abstracting from variable capacity utilization (c) adding inventory data to the US investment time series and (d) assuming extreme export price stickiness of 10 quarters duration.

4.2 Altering the Choice of Structural Shocks

The estimated importance of specific shocks could also depend on the assumptions made about other shocks that are or are not introduced into the estimations. Hence, we have estimated a number of models that are more fundamentally different from the baseline model. In all these checks, we maintain a strict equality between the number of observable data series and the number of the shocks used to fit the series.

The first specification we implement in this subset of checks, is the removal of the PPP shock of Lubik and Schorfheide (2005) and the highly volatile nominal exchange rate

[24] The original BKK framework used a two-good two-country model while the empirical papers use tradable differentiated intermediate varieties and a non-traded aggregated good in each country. Notably, the trade balance impulse responses to structural shocks are weaker than in the baseline case.

series from the estimation. This check is motivated by the fact that the PPP innovation absorbs more than 75 percent of the forecast volatility of the nominal exchange rate in the baseline model while affecting no other variable significantly. This disconnect of exchange rate dynamics from the fundamentals has also been observed in Lubik and Schorfheide (2005). Not surprisingly, as reported in the second column of Table 5, removing this shock and the nominal exchange rate series does not alter the variance decomposition for the trade balance.

The next set of checks enable a closer comparison with Bergin (2006) and De Walque *et al.* (2005), our precedents in the empirical open economy literature who find no substantive effect of investment shocks on US trade balance fluctuations, albeit for contrasting reasons. An important caveat to the exercises that we pursue here is that none of the modelling approaches are nested within each other in terms of either structural features or statistical implementation and it is not our intention to replicate their results. However, these checks may still indicate the potential sources of discrepancy.

Bergin (2006) uses maximum likelihood techniques to estimate a symmetric two-country model using five observable data series on US and a rest of the G-7 aggregate and finds that UIP shocks are the main drivers of the US current account. Unlike in our case, he does not use investment shocks, motivating our decision to estimate a version of our model abstracting from investment shocks and data. Firstly, we use the BKK trade specification of Bergin along with a relative US import preference shock to the US Armington aggregator function, while removing the PPP shock.[25] Subsequently, in the estimation, we use data on output, consumption, interest rate for the US and the RoW together with the intra-OECD trade balance and exchange rate. The corresponding shocks we employ are those to UIP, the relative import shock and the home and foreign TFP, time impatience and monetary policy shocks. As presented in the third column of Table 5, consistent with the findings of Bergin (2006), the UIP shock becomes the dominant shock in the decomposition, contributing about 40 percent while the relative import preference shock contributes 18 percent. Time impatience shocks also have stronger effects now contributing together about 25 percent, compared to less than 1 percent in the baseline case. This exercise suggest that, when fundamental investment shocks are omitted

[25] The share of imports is set at 0.15. The import-share preference shock worsens the trade balance and is the mirror-image of the home-bias preference shock used by Bergin that improves it. To conform with Bergin's model, we also removed habit formation, variable capacity utilization and wage frictions, data and shocks in this check.

from the analysis, the contribution of these shocks to the trade balance is mainly absorbed by UIP shocks and to a lesser extent time impatience shocks. This proposition is confirmed when we re-estimate the Bergin-specification adding only investment data and investment-specific technological shocks. As shown in Table 5, investment shocks become again the dominant source, whereas the joint contribution of UIP and time impatience shocks declines from 65 percent to approximately 20 percent.

De Walque *et al.* (2005) examine the US and Eurozone trade balances in a large-scale two-country model estimated with twenty two macroeconomic time series and shocks. In line with our results, they find that UIP shocks contribute only about 20 percent of the US trade balance volatility at a one year horizon but, in contrast to our results, they do not find that investment shocks are important even though they employ these shocks and relevant data series. What explains this difference? First, they use the aggregate BKK absorption-based trade specification, which already slightly reduces the contribution of investment shocks to the variability of the trade balance, as discussed in Section 4.1. Second, unlike our study, De Walque *et al.* (2005) do not consider the bilateral balance between the two regions but instead focus on the actual trade balances. In their trade structure, aggregate US (Eurozone) exports are demanded by the Eurozone (US) and an unmodelled Rest of the World that is captured through export demand shocks. These RoW export demand shocks enter the definition of the US trade balance directly and turn out to account for about half of its forecast variance, which automatically dilutes the contribution of all other shocks. Note that we do not have this demand from omitted countries since we use the bilateral balance between the two regions.

To analyze the role of this omitted RoW export demand shocks more carefully, we have also estimated a model with the BKK aggregate absorption based trade specification together with an additional demand shock for US exports. Specifically, we add an AR(1) shock ε^X to the export demand function, $\hat{Y}^*_{Ht} - \hat{Y}^*_{Ft} = -\mu \widehat{ToT}^*_t + \varepsilon^X_t$ such that $\varepsilon^X_t = \rho_X \ \varepsilon^X_{t-1} + \eta^X_t$.[26] Observe that in our case, using the bilateral balance between the two regions, we cannot assign the 'demand from omitted countries' structural interpretation to this disturbance, although just as in the original paper, the shock acts as the US trade balance's own driving force. The fifth column of Table 5 shows the results in case we continue to assume an import share of GDP which is 15 percent. In this case, the export demand shock contributes about 21 percent of the forecast variance, whereas investment

[26] Note that in De Walque *et al.*(2005), this shock affects the export market clearing equation.

shocks remain the major driving factor accounting for about 40 percent. Strikingly, if we also *estimate* the import share of GDP as in De Walque *et al.* (2005), the posterior of this parameter turns out to be close to 1 percent, and the decomposition changes dramatically. The export shock now contributes 75 percent of the forecast variance, whereas investment shocks account for only 5 percent (Table 5, column 6). The main reason is that the very low import share makes the two regions behave almost as autarkic economies. The trade balance becomes a disconnected variable driven most potently by its own shock, with the more fundamental shocks having a minimal impact. The estimated import share of 1 percent obtained in this experiment is, however, very unrealistic given an unconditional import share of about 15 percent observed in US data. De Walque *et al.* (2005) use a very restrictive prior centered on the share of 5 percent that is accounted by European exports in US GDP and their posterior estimates are exactly the same as the prior. In contrast, we assigned a relatively loose prior as for all our other parameters that span the unit interval.[27] The assumed degree of openness is crucial in the international transmisson of shocks and imposing the realistic value of 15 percent for the share of imports in total GDP, as in this check, results in investment shocks dominating US trade balance variability.[28]

Finally, a modelling feature of De Walque *et al.* (2005) that may contribute to the suppression of the relative influence of investment shocks is the introduction of risk premium shocks that generate a positive comovement between consumption and investment and contribute almost 20 percent of the trade balance forecast variance in their analysis. Our final check involves the introduction of these shocks into our baseline model. To do so, we supplant the time-impatience shock in Euler Equation 7 with the risk premium shock *à la* SW (2007) that appears as a wedge between the risk-free interest rate set by the monetary authority and the rate that faces the private agent and helps to fit two asset-pricing conditions - for consumption as well as the capital stock - simultaneously.

$$\hat{C}_t = \frac{1}{1+\vartheta}\mathbf{E}_t\hat{C}_{t+1} + \frac{\vartheta}{1+\vartheta}\hat{C}_{t-1} - \frac{1}{\sigma_C}\frac{(1-\vartheta)}{(1+\vartheta)}\left(\hat{R}_t - \mathbf{E}_t\hat{\pi}_{Ct+1} - \varepsilon_t^{RP}\right) \tag{22}$$

[27] Justiniano and Preston (2010) document that posterior estimates of the openness parameter can decline to implausibly low values if loose priors are assigned. De Walque *et al.* (2005) use a very informative Normal prior of mean 0.05 and standard deviation 0.01 whereas we assigned a much looser Beta distribution of mean 0.50 and standard deviation 0.15.

[28] For further confirmation, we estimated a specification in which we *fix* the import share at 5 percent. Already the export shock is the most dominant shock contributing 30 percent of the forecast variance while the US investment shock accounts for only 17 percent. The latter declines even further to 7 percent if we also introduce risk premium shocks as in De Walque *et al.* (2005), which is our next robustness check.

$$\widehat{TQ}_t = (1 - \beta(1-\delta))\,\mathbf{E}_t\hat{r}^k_{t+1} + \beta(1-\delta)\,\mathbf{E}_t\widehat{TQ}_{t+1} - \left(\hat{R}_t - \mathbf{E}_t\hat{\pi}_{Ct+1} - \varepsilon^{RP}_t\right) \qquad (23)$$

The stimulus on investment via Equation 23 that determines the marginal value of physical capital is achieved by a lowering of the external finance premium for investors. The additional effect exerted by the risk premium shock on investment makes this disturbance a potential candidate in diminishing the overwhelming influence of the investment shock on the trade balance. The last column in Table 5 shows that this is indeed the case. The combined effect of these strong demand shocks come to about 20 percent in stark contrast to the time impatience shocks that contribute less than 1 percent in the baseline case. The strong influence of the US investment shock continues to hold at 28 percent. In contrast, the influence of the RoW investment shock is diminished by the RoW risk premium shock. An examination of the impulse responses (not exhibited) reveals that in both regions, the risk premium shock induces stronger responses in investment than in consumption. This is not surprising given the well-known higher sensitivity of investment to changes in the real interest rate (that the risk premium shock augments). However due to the much higher degree of persistence estimated in the RoW risk premium shock, it gives a stronger push to RoW investment than does the US analog to US investment (See final column of Table 6). The additional impetus given by the RoW risk premium shock to regional investment reflects in a stronger reaction from investment net-traded volumes than that induced by the US analog. On the other hand, due to the higher estimated adjustment cost and lower persistence in the RoW investment shock, RoW investment reacts relatively less in response, than US investment does to the US investment shock even as consumption barely moves in either case. Consequently, this results in a relatively lower impact of the RoW investment shock on investment net-traded volumes and hence the trade balance. While this finding makes it difficult to interpret the nature of this external disturbance, both the RoW risk premium in this robustness check and the potent RoW investment shock in the baseline model capture the importance of investment dynamics in the RoW for the US trade balance. However, even with the introduction of risk premium shocks, the home and foreign investment shocks together contribute about 43 percent of the variance of the trade balance.

In sum, the dominance of investment shocks turns out to be a very robust feature. This remains also when we add or remove other shock and data series to the baseline model, such as (a) using flexible labor markets while avoiding real wage data and corresponding mark-up shocks (b) assuming that the government consumes a fixed proportion of output and using domestic Phillips curve price mark-up shocks instead of fiscal shocks and (c) using domestic and export price mark-up shocks along with US export-import price data series.

5 Conclusions

This paper highlights the influence of investment-specific technological shocks, relative to other structural shocks used in the literature, on the bilateral trade balance between the US and a trade-weighted aggregate of sixteen OECD economies in a two-country DSGE model estimated with Bayesian methods. The relative strength of the investment shock, which holds through a wide array of model specifications, is primarily due to the strong negative response it evokes from net export volumes that dominates a positive expenditure-switching effect arising from the deterioration of the relative terms of trade. In contrast, neutral technological shocks have much lower influence on the variance as the impact of rising domestic consumption and investment is dominated by the expenditure-switching effect. The latter effect is strong enough to induce a counter-factual procyclicality in the trade balance. On the other hand, this paper also provides strong evidence on the impact of external disturbances on the US trade balance, as seen in the contributions of investment-specific shocks and risk premium shocks from the Rest of the World. Despite the dichotomy in the structural interpretation of these external disturbances, a striking feature of the channels of transmission of both shocks to the trade balance is the role of investment.

A Appendix

A.1 Data Series

All raw series are seasonally adjusted by the Census X12 method. We use the Direction of Trade Statistics (DOTS) database of the International Monetary Fund (IMF) to construct the aggregated bilateral trade balance (net exports in US dollars) between the US and the 16 OECD trade partners over 1980Q1-2005Q4. The series for nominal GDP, nominal consumption, nominal gross fixed capital formation, nominal interest rates, nominal wages and nominal exchange rates for the US, Canada, Japan, Korea and the UK are obtained from the International Financial Statistics Database (IFS) of the IMF. For the Eurozone series, we use data from the Area Wide Model (Fagan *et al.* 2001).[29] Shares of each individual economy are computed by dividing the sum of imports and exports with the individual economy by aggregate trade. We use these time-varying weights to aggregate individual economy series to make the RoW (Canada generally gets the highest weight while Korea gets the lowest). The trade-share weights are also used to construct a bilateral nominal exchange rate between the US and the RoW, which exhibits a correlation coefficient of 0.81 with the IMF's Nominal Effective Exchange Rate.[30] We multiply the natural logarithms of real consumption, real GDP, real gross fixed capital formation, the GDP deflator, the real wage and the nominal exchange rate by 100. These series are fed into the model in demeaned first differences. The demeaned nominal interest rates are divided by 4 to translate them into quarterly terms. The nominal interest rates and the linearly detrended trade balance to US GDP ratio enter the estimation in levels.

A.2 Estimation

We use 525000 iterations of the Random Walk Metropolis Hastings algorithm to simulate the posterior distributions and achieve acceptance rates of about 40 percent in all our specifications. We monitor the convergence of the marginal posterior distributions using CUMSUM statistics as defined by Bauwens *et al.* (1999). We discard the initial 25000 draws to compute the posterior moments in each case. The distributions of impulse response functions and variance decompositions that we present are computed from 150 random draws from the posterior. This strategy ensures that our results are not contingent on a particular vector of parameter values such as the posterior median or the mode.

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[29] We use the best available substitutes for the nominal interest rate for each economy. For Canada and the United Kingdom, we use the Treasury Bill rate, for Japan we use the government bond yield, and for Korea, we use the discount rate. Finally, the nominal interest rate series (STN) from the Area Wide Model is used.

[30] The pre-EMU Euro-Dollar exchange rate was constructed using the methodology of Lubik and Schorfheide (2005) harnessing country-weights from the Area Wide Model.

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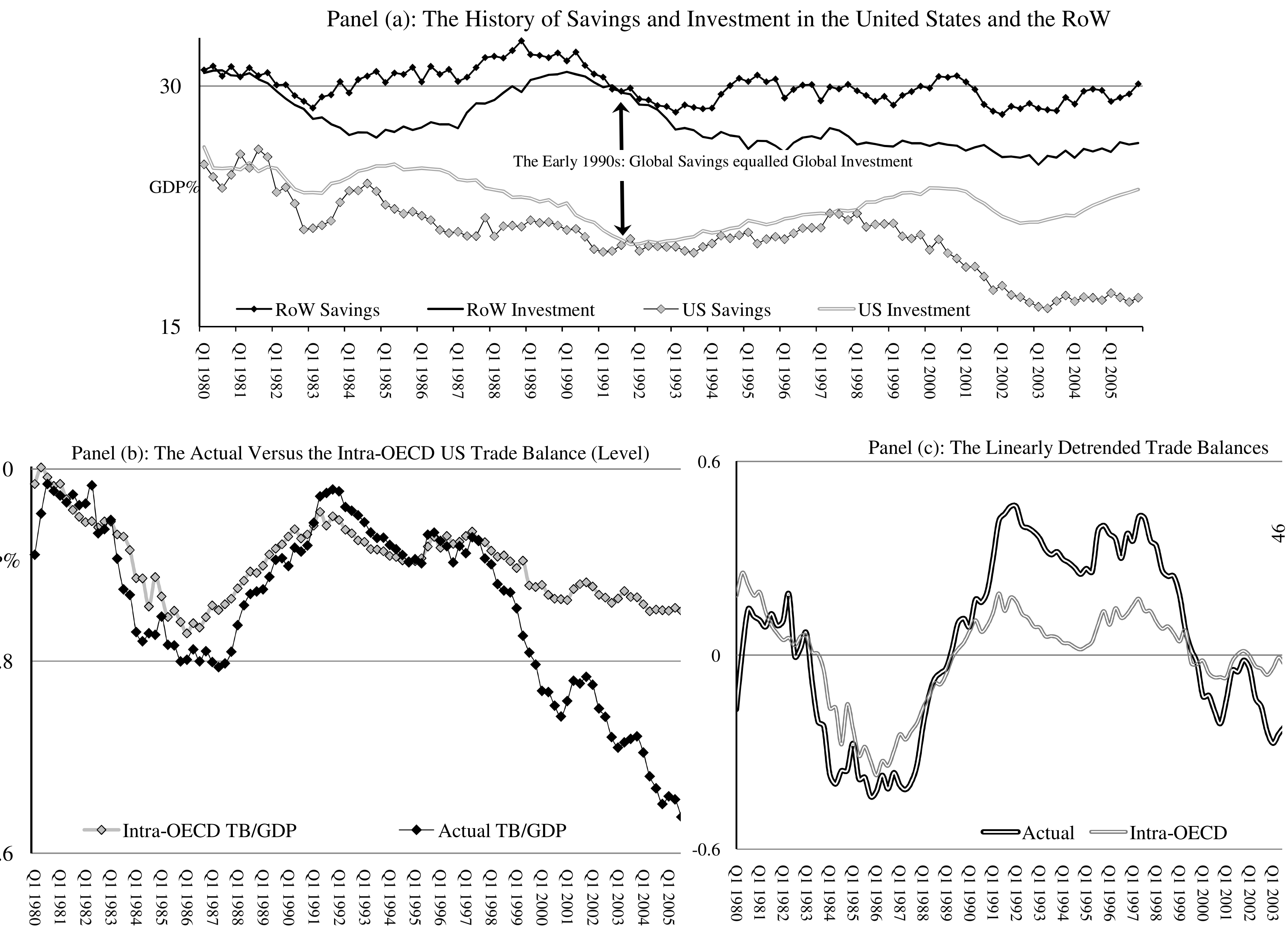

Figure 1

Note: The Rest of the World (RoW) is a trade-weighted aggregate of the United Kingdom, Canada, Japan, Korea and 12 members of the Euro-Zone. The investment ra
measured as (I/Y-G) and the savings ratio is measured as (Y-C-T /Y-G).

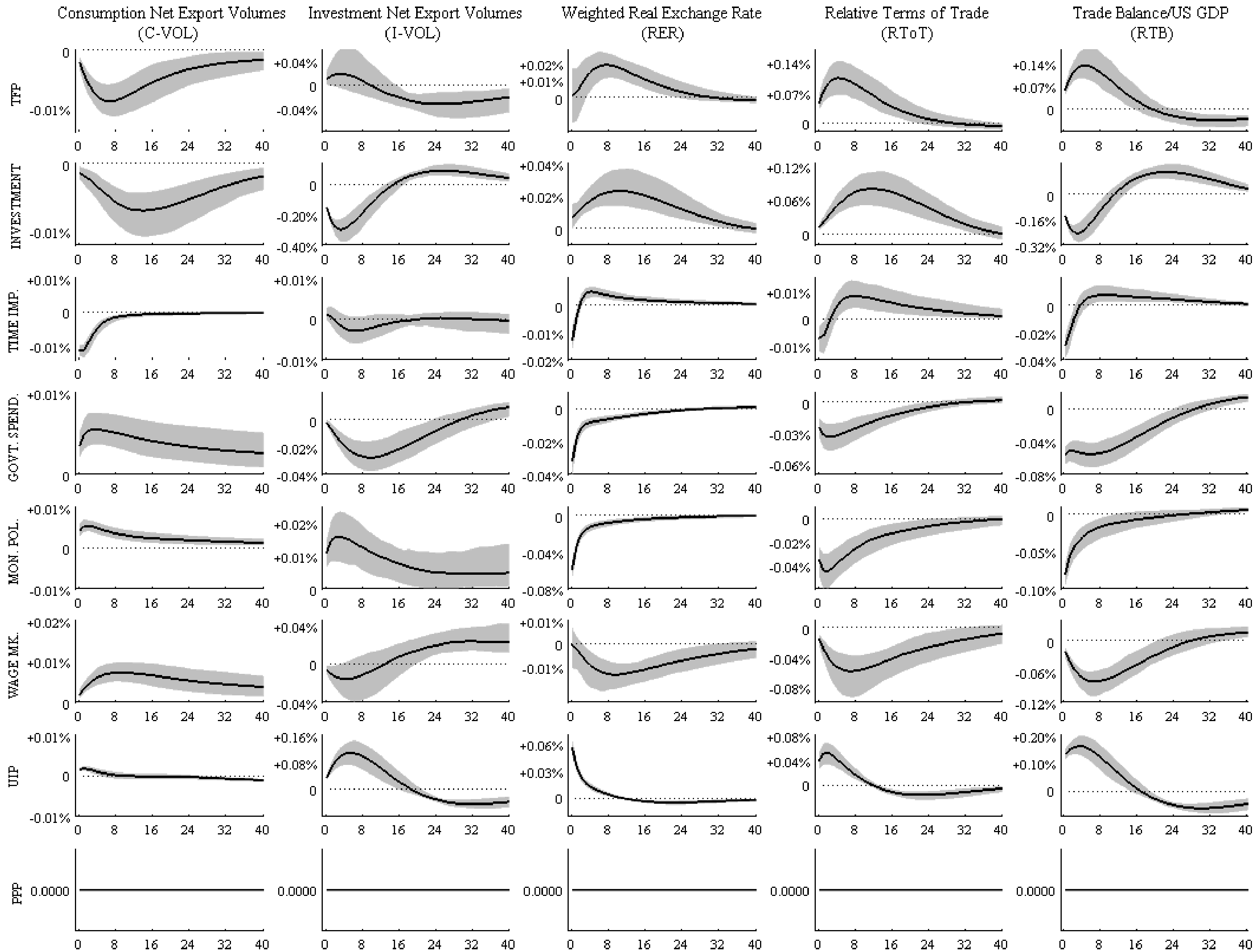

Figure 2: The Dynamic Responses of the Components of the Trade Balance to a one Standard Deviation Shock

Note: The median IRF (thick black line) and the 5th and 95th percentiles (shaded area) are based on 150 random draws from the posterior distribution. Each IRF is measured in percentage deviations from steady-state.

Table 1: Unconditional Moments of the Data

Correlation between Actual and Intra-OECD US Trade Balances

Levels	0.85
Detrended	0.79

Observable Series

Series	**US** Mean	**US** SD	**RoW** Mean	**RoW** SD	**Model US Variable** (Filtered Data)
Real Consumption Growth	0.83	0.60	0.64	0.50	$\Delta\hat{C}_t + \xi_C \Delta\widehat{ToT}_t$
Real Investment Growth	0.63	1.73	0.60	1.27	$\Delta\hat{I}_t + \xi_I \Delta\widehat{ToT}_t$
Real GDP Growth	0.71	0.70	0.65	0.55	$\Delta\hat{Y}_{Ht}$
Real Wage Inflation	0.08	0.34	0.26	0.46	$\Delta\widehat{w}_t$
GDP Deflator Inflation	0.82	0.53	0.82	0.48	$\Delta\hat{\pi}_{Ht}$
Nominal Interest Rate	1.66	0.95	1.70	0.85	$\Delta\hat{R}_t$
Nominal Depreciation of USD	-0.03	2.71	-	-	$\Delta\widehat{NER}_t$
Intra-OECD TB/GDP	-0.38	0.16	-	-	$\Delta\widehat{RTB}_t$
Actual US TB/GDP	-0.57	0.37	-	-	$\Delta\widehat{RTB}_t$

Note: We adjust for the terms of trade we link aggregate consumption and investment to the data. For example, the level of real consumption, as we measure it in the data is given as $C^{DATA} = \frac{P_{CPI}}{P_{GDP}} C^{MODEL}$. Thus, because the CPI has a component that depends on the import-intensity ξ_C, the terms of trade influence real aggregate consumption. As the observables are fed into the model in first differences, the changes in the terms of trade are accounted for.

Table 2: Prior and Posterior Distributions in Baseline Estimation

ESTIMATED STRUCTURAL PARAMETERS

Symbol	Description	Prior (P1, P2)	Posterior Med	Posterior SD
μ	Trade Elasticity	G (1.50, 0.75)	1.90	0.23
σ_C	US Utility Curvature	G (2.00, 0.75)	2.16	0.33
σ_C^*	RoW Utility Curvature	G (2.00, 0.75)	2.91	0.38
ϑ	US External Habit	B (0.50, 0.15)	0.52	0.11
ϑ^*	RoW External Habit	B (0.50, 0.15)	0.08	0.04
ψ	US Investment Adj. Cost	N (4.00, 1.00)	5.92	0.85
ψ^*	RoW Investment Adj. Cost	N (4.00, 1.00)	6.66	0.84
φ	US Capacity Util. Cost	B (0.50, 0.15)	0.53	0.10
φ^*	RoW Capacity Util. Cost	B (0.50, 0.15)	0.50	0.10
θ_P	US GDP Deflator Calvo	B (0.50, 0.15)	0.77	0.04
θ_P^*	RoW GDP Deflator Calvo	B (0.50, 0.15)	0.14	0.05
ι_P	US Price Indexation	B (0.50, 0.15)	0.21	0.08
ι_P^*	RoW Price Indexation	B (0.50, 0.15)	0.36	0.14
θ_W	US Wage Calvo	B (0.50, 0.15)	0.92	0.03
θ_W^*	RoW Wage Calvo	B (0.50, 0.15)	0.78	0.07
ι_W	US Wage Indexation	B (0.50, 0.15)	0.65	0.09
ι_W^*	RoW Wage Indexation	B (0.50, 0.15)	0.11	0.05
ϕ_π	US Mon. Pol. (Inflation)	G (0.50, 0.25)	1.66	0.17
ϕ_π^*	RoW Mon. Pol. (Inflation)	G (0.50, 0.25)	1.57	0.17
ϕ_y	US Mon. Pol. (GDP)	G (0.50, 0.25)	0.02	0.01
ϕ_y^*	RoW Mon. Pol. (GDP)	G (0.50, 0.25)	0.04	0.02
$\phi_{\Delta y}$	US Mon. Pol. (GDP change)	G (0.50, 0.25)	0.34	0.04
$\phi_{\Delta y}^*$	RoW Mon. Pol. (GDP change)	G (0.50, 0.25)	0.38	0.05
ρ_{MON}	US Interest Smoothing	B (0.50, 0.15)	0.73	0.03
ρ_{MON}^*	RoW Interest Smoothing	B (0.50, 0.15)	0.83	0.03

SHOCKS AR(1), MA(1)

Symbol	Prior (P1, P2)	Posterior Med	Posterior SD
ρ_{TI}	B (0.50, 0.15)	0.48	0.14
ρ_{TI}^*	B (0.50, 0.15)	0.82	0.05
ρ_{INV}	B (0.50, 0.15)	0.71	0.06
ρ_{INV}^*	B (0.50, 0.15)	0.65	0.08
ρ_{UIP}	B (0.50, 0.15)	0.85	0.03
ρ_{TFP}	B (0.50, 0.15)	0.92	0.02
ρ_{TFP}^*	B (0.50, 0.15)	0.98	0.03
ρ_{GOV}	B (0.50, 0.15)	0.98	0.01
ρ_{GOV}^*	B (0.50, 0.15)	0.97	0.02
ρ_{WM}	B (0.50, 0.15)	0.60	0.10
ρ_{WM}^*	B (0.50, 0.15)	0.92	0.04
ν_{WM}	B (0.50, 0.15)	0.45	0.13
ν_{WM}^*	B (0.50, 0.15)	0.80	0.08
SHOCK INNOVATIONS			
$100\sigma_{TI}$	U(0.001, 10)	0.17	0.04
$100\sigma_{TI}^*$	U(0.001, 10)	0.06	0.02
$100\sigma_{INV}$	U(0.001, 10)	0.40	0.05
$100\sigma_{INV}^*$	U(0.001, 10)	0.33	0.05
$100\sigma_{UIP}$	U(0.001, 10)	0.16	0.03
$100\sigma_{TFP}$	U(0.001, 10)	0.78	0.21
$100\sigma_{TFP}^*$	U(0.001, 10)	0.42	0.05
$100\sigma_{MON}$	U(0.001, 10)	0.28	0.03
$100\sigma_{MON}^*$	U(0.001, 10)	0.21	0.03
$100\sigma_{GOV}$	U(0.001, 10)	0.44	0.03
$100\sigma_{GOV}^*$	U(0.001, 10)	0.31	0.02
$100\sigma_{WM}$	U(0.001, 10)	0.13	0.02
$100\sigma_{WM}^*$	U(0.001, 10)	0.13	0.02
$100\sigma_{PPP}$	U(0.001, 10)	3.04	0.22

CALIBRATED STRUCTURAL PARAMETERS

β	Discount Factor	0.99	θ_H^*	US Export Calvo	0.5
α	Share of Capital Services in Production	1/3	θ_F	RoW Export Calvo	0.5
δ	Quarterly Rate of Capital Depreciation	0.025	ξ_C	Import-share of consumption	0.039
χ_P	Substitution Elasticity of Goods Varieties	10	ξ_I	Import-share of investment	0.419
χ_W	Substitution Elasticity of Labour Varieties	10	Ξ_C	Implied steady-share of consumption in GDP	0.61
σ_N	Inverse of Frisch Elasticity	2	Ξ_I	Implied steady-share of investment in GDP	0.21
κ	Cost of adjusting foreign assets	0.001			

Note: G= Gamma, B= Beta, U= Uniform and N= Normal distributions. P1= Mean and P2= Standard Deviation for all distributions except for the Uniform in which case they indicate the lower and upper bounds respectively. Posterior moments are computed using 500000 draws from the distribution simulated by the Random Walk Metropolis algorithm.

Table 3: Forecast Error Variance Decomposition in Baseline Estimation

VARIABLES →	**Trade Balance**				**US Output**				**US Consumption**				**US Investment**			
SHOCKS ↓	Forecast Horizon in Quarters				Forecast Horizon in Quarters				Forecast Horizon in Quarters				Forecast Horizon in Quarters			
	0 Q	4 Q	8 Q	40 Q	0 Q	4 Q	8 Q	40 Q	0 Q	4 Q	8 Q	40 Q	0 Q	4 Q	8 Q	40 Q
US Shocks																
TFP	4.36	9.03	11.64	10.19	4.00	27.72	34.15	29.53	4.28	18.76	25.94	20.74	0.74	2.57	5.27	14.32
Investment	24.40	34.78	31.48	36.65	15.77	26.65	28.81	29.72	0.17	1.48	6.85	26.33	94.69	90.24	84.37	54.66
Time Impatience	1.26	0.25	0.18	0.15	24.91	9.00	4.68	2.12	71.51	40.34	24.22	7.55	0.03	0.02	0.05	0.15
Govt. Spending	4.23	2.22	2.59	2.71	28.03	7.33	4.63	4.94	9.22	14.65	14.88	12.84	0.14	0.09	0.09	0.32
Mon. Policy	8.95	2.20	1.60	1.06	18.57	13.94	9.54	5.75	11.41	12.48	9.93	5.29	1.53	1.49	1.65	2.03
Wage Mark-up	0.71	2.45	4.12	4.72	2.48	10.37	14.77	23.62	2.93	11.68	17.49	22.98	0.10	0.48	1.29	8.82
RoW Shocks																
TFP	2.05	1.93	1.89	1.58	0.92	0.40	0.19	0.28	0.05	0.04	0.03	0.24	0.18	0.41	0.66	1.66
Investment	19.62	23.51	20.80	18.89	2.65	3.02	2.34	2.30	0.16	0.18	0.32	2.66	0.55	0.54	0.39	5.93
Time Impatience	1.64	0.54	0.39	0.26	0.24	0.09	0.04	0.02	0.00	0.00	0.00	0.01	0.04	0.05	0.06	0.06
Govt. Spending	3.18	1.70	1.75	1.53	0.24	0.11	0.05	0.15	0.03	0.03	0.03	0.14	0.19	0.41	0.63	1.02
Mon. Policy	7.01	2.30	1.79	1.21	0.52	0.22	0.10	0.23	0.01	0.01	0.01	0.16	0.28	0.53	0.72	0.98
Wage Mark-up	0.21	2.18	4.03	5.53	0.09	0.15	0.11	1.05	0.07	0.15	0.15	0.91	0.14	0.67	1.66	7.13
Open-Economy Shocks																
UIP	22.37	16.91	17.73	15.50	1.57	1.00	0.57	0.28	0.16	0.20	0.15	0.15	1.39	2.51	3.17	2.92
PPP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: The influence of each shock at forecast horizon k is measured by the variability generated by a unit standard deviation shock at time 0, cumulated over the interval 0 to k. This is then divided by the aggregate variability induced by all the shocks and expressed in percentage terms. We report the mean of a distribution of variance decompositions computed from 150 random draws from the posterior distribution (Each column adds to 100). Confidence bands for the variance decompositions are available on request.

Table 4: 4Q-Ahead Trade Balance Variance Decompositions with Baseline Shocks

SPECIFICATIONS →	**Baseline**	**Actual TB**	**80-00**	**Complete**	**Import-Cost**	**BKK**
SHOCKS ↓	(C-I)	(C-I)	(C-I)	(C-I)	(C-I)	(Y)
US						
TFP	9.03	9.04	10.00	9.95	8.17	0.95
Investment	34.78	35.26	37.43	25.92	36.36	28.86
Time Impatience	0.25	0.27	0.36	0.18	0.16	6.03
Govt. Spending	2.22	1.90	2.10	4.60	1.66	11.48
Monetary Policy	2.20	1.94	1.80	2.47	1.02	2.48
Wage Mark-up	2.45	2.54	2.96	3.75	2.31	0.40
ROW						
TFP	1.93	1.87	3.33	2.24	1.53	0.39
Investment	23.51	22.66	13.68	28.08	25.18	21.01
Time Impatience	0.54	0.55	0.79	1.21	0.31	3.85
Govt. Spending	1.70	1.68	2.05	1.25	0.76	3.24
Monetary Policy	2.30	2.26	3.06	2.02	1.24	1.27
Wage Mark-up	2.18	2.25	2.60	2.57	1.72	0.20
OPEN-ECONOMY						
UIP	16.91	17.79	19.82	15.75	19.58	19.81
PPP	0.00	0.00	0.00	0.00	0.00	0.00

Note: All models using differential import-intensities for consumption and investment are denoted by **(C-I)** while the others using the traditional BKK aggregate absorption-based specification is denoted by **(Y)**. **'Baseline'** indicates the baseline model. **'Actual TB'** denotes the use of the actual series on the US trade balance. **'80-00'** uses a shorter sample over 1980-2000, the time span during which we observe that the intra-OECD trade balance tracks the actual series quite well. **'Complete'** refers to the case where international consumption risk is shared efficiently, pinning down the CPI-based real exchange rate to relative consumption. **'Import-Cost'** uses adjustment costs for imports and hence differentiates between short-run and long-run trade-elasticities. **'BKK'** employs the Backus, Kydland and Kehoe (1994) aggregation of home and imported goods specified in terms of aggregate absorption.

Table 5: 4Q-Ahead Trade Balance Variance Decompositions with Other Shocks

SPECIFICATIONS → SHOCKS ↓	**Baseline** (C-I)	**PPP** (C-I)	**B** (Y)	**B-IST** (Y)	**DSW-15%** (Y)	**DSW-1%** (Y)	**Risk-P** (C-I)
US							
TFP	9.03	8.02	3.99	1.99	5.72	0.39	8.05
Investment	34.78	35.41	-	28.49	22.84	3.05	28.35
Time Impatience	0.25	0.21	10.12	2.05	5.54	0.81	-
Govt. Spending	2.22	2.00	-	-	3.77	1.57	1.87
Monetary Policy	2.20	1.98	5.75	1.62	1.27	0.28	1.67
Wage Mark-up	2.45	2.15	-	-	1.23	0.10	1.82
Risk-Premium	-	-	-	-	-	-	5.35
Price Mark-up	-	-	-	-	-	-	-
Export Price Mark-up	-	-	-	-	-	-	-
ROW							
TFP	1.93	1.71	2.30	0.57	2.73	0.14	1.34
Investment	23.51	24.77	-	28.19	17.25	1.96	14.49
Time Impatience	0.54	0.43	15.38	1.77	2.26	0.45	-
Govt. Spending	1.70	1.36	-	-	2.11	0.67	1.07
Monetary Policy	2.30	1.82	4.16	1.40	1.25	0.12	1.47
Wage Mark-up	2.18	2.05	-	-	2.12	0.09	1.36
Risk-Premium	-	-	-	-	-	-	14.13
Price Mark-up	-	-	-	-	-	-	-
Export Price Mark-up	-	-	-	-	-	-	-
OPEN-ECONOMY							
UIP	16.91	18.10	40.06	16.09	11.21	15.63	19.02
PPP	0.00	-	-	-	-	-	0.00
US Import Preference	-	-	18.24	17.82	-	-	-
Export Shock	-	-	-	-	20.70	74.75	-

Note: All models using differential import-intensities for consumption and investment are denoted by **(C-I)** while the others using the traditional aggregate absorption-based specification is denoted by **(Y).** Whenever a shock is deactivated, the variance contribution is indicated by a '-'. **'Baseline'** indicates the baseline model. **'PPP'** denotes the case where we do not use the PPP shock of Lubik and Schorfheide (2005) as well as the exchange rate data. **'B'** strips down the baseline model to a specification that is estimated without investment shocks, in the spirit of Bergin (2006). **'B-IST'** adds investment shocks and data (while not using variable capacity utilization) to this Bergin-type specification. **'DSW-15%'** employs the export shock as in De Walque, Smets and Wouters (2005) while fixing the import-intensity at 15 percent as in Backus, Kydland and Kehoe (1994). In **'DSW-1%'**, the import-intensity is estimated at 1 percent, with all other features preserved as in the previous specification. **'Risk-P'** uses the Smets and Wouters (2007) risk premium shock which generates comovement between consumption and investment.

Table 6: Prior and Posterior Distributions of Structural Parameters

Symbol	Description	PRIOR (P1, P2)	POSTERIORS (Median; Standard Deviation) IN VARIOUS SPECIFICATIONS — Retaining Baseline Shocks: Baseline	Actual-TB	80-00	Complete	Import-Cost	BKK	Altering the Choice of Shocks: PPP	B	B-IST	DSW-15%	DSW-1%	Risk-P
μ	Trade Elasticity	G (1.50, 0.75)	1.87; 0.23	1.90; 0.23	2.19; 0.31	1.79; 0.19	2.10; 0.34	0.89; 0.03	1.64; 0.20	0.72; 0.02	0.71; 0.02	0.67; 0.01	0.84; 0.11	1.87; 0.23
σ_C	US Utility Curvature	G (2.00, 0.75)	2.20; 0.34	2.06; 0.34	1.61; 0.32	2.31; 0.32	2.26; 0.37	2.25; 0.34	2.27; 0.34	2.69; 0.49	2.43; 0.40	3.40; 0.62	2.22; 0.42	2.03; 0.27
σ_C^*	RoW Utility Curvature	G (2.00, 0.75)	2.94; 0.39	2.85; 0.38	2.49; 0.40	3.18; 0.45	2.94; 0.41	2.63; 0.39	2.98; 0.39	2.70; 0.50	3.26; 0.54	3.64; 0.52	2.94; 0.45	2.46; 0.30
ϑ	US External Habit	B (0.50, 0.15)	0.52; 0.11	0.55; 0.11	0.60; 0.10	0.44; 0.12	0.60; 0.10	0.38; 0.11	0.51; 0.11	-	-	0.29; 0.13	0.69; 0.09	0.59; 0.08
ϑ^*	RoW External Habit	B (0.50, 0.15)	0.08; 0.04	0.08; 0.04	0.11; 0.07	0.20; 0.12	0.10; 0.05	0.09; 0.04	0.09; 0.04	-	-	0.13; 0.05	0.11; 0.05	0.12; 0.05
ψ	US Investment Adj. Cost	N (4.00, 1.00)	5.91; 0.87	5.89; 0.87	5.42; 0.89	5.86; 0.88	6.12; 0.85	4.37; 0.91	5.99; 0.88	5.04; 0.87	5.71; 0.89	5.07; 0.90	4.71; 0.91	5.54; 0.83
ψ^*	RoW Investment Adj. Cost	N (4.00, 1.00)	6.65; 0.85	6.66; 0.84	6.29; 0.81	6.99; 0.84	6.70; 0.83	4.40; 0.97	6.67; 0.84	6.10; 0.82	5.51; 1.00	4.56; 1.00	4.46; 1.12	5.98; 0.84
φ	US Capacity Util.Cost	B (0.50, 0.15)	0.54; 0.10	0.56; 0.10	0.51; 0.10	0.51; 0.10	0.66; 0.10	0.53; 0.09	0.54; 0.10	-	-	0.60; 0.09	0.75; 0.10	0.54; 0.10
φ^*	RoW Capacity Util. Cost	B (0.50, 0.15)	0.50; 0.10	0.52; 0.10	0.46; 0.11	0.50; 0.13	0.57; 0.12	0.47; 0.08	0.50; 0.11	-	-	0.63; 0.10	0.78; 0.09	0.57; 0.11
θ_P	US GDP Deflator Calvo	B (0.50, 0.15)	0.77; 0.04	0.77; 0.04	0.76; 0.05	0.79; 0.04	0.76; 0.05	0.80; 0.04	0.78; 0.04	0.78; 0.03	0.75; 0.03	0.71; 0.06	0.82; 0.04	0.78; 0.04
θ_P^*	RoW GDP Deflator Calvo	B (0.50, 0.15)	0.13; 0.05	0.14; 0.05	0.13; 0.05	0.14; 0.06	0.15; 0.06	0.13; 0.05	0.14; 0.05	0.41; 0.07	0.36; 0.07	0.19; 0.05	0.23; 0.07	0.14; 0.05
ι_P	US Price Indexation	B (0.50, 0.15)	0.20; 0.08	0.20; 0.08	0.33; 0.11	0.18; 0.08	0.20; 0.08	0.14; 0.06	0.20; 0.08	0.24; 0.11	0.24; 0.10	0.18; 0.09	0.17; 0.07	0.19; 0.08
ι_P^*	RoW Price Indexation	B (0.50, 0.15)	0.37; 0.14	0.37; 0.15	0.37; 0.15	0.36; 0.14	0.36; 0.14	0.41; 0.15	0.37; 0.15	0.38; 0.15	0.37; 0.15	0.43; 0.14	0.35; 0.14	0.37; 0.15
θ_W	US Wage Calvo	B (0.50, 0.15)	0.92; 0.04	0.90; 0.04	0.82; 0.07	0.92; 0.03	0.92; 0.04	0.95; 0.02	0.93; 0.03	-	-	0.93; 0.03	0.86; 0.05	0.91; 0.04
θ_W^*	RoW Wage Calvo	B (0.50, 0.15)	0.78; 0.07	0.77; 0.07	0.77; 0.07	0.79; 0.06	0.76; 0.07	0.79; 0.05	0.78; 0.07	-	-	0.77; 0.07	0.70; 0.07	0.74; 0.07
ι_W	US Wage Indexation	B (0.50, 0.15)	0.65; 0.09	0.64; 0.10	0.60; 0.11	0.64; 0.09	0.64; 0.09	0.67; 0.08	0.66; 0.09	-	-	0.65; 0.08	0.67; 0.10	0.67; 0.09
ι_W^*	RoW Wage Indexation	B (0.50, 0.15)	0.11; 0.05	0.11; 0.05	0.13; 0.05	0.11; 0.05	0.12; 0.05	0.14; 0.06	0.11; 0.05	-	-	0.21; 0.08	0.14; 0.06	0.11; 0.04
ϕ_π	US Mon. Pol. (Inflation)	G (0.50, 0.25)	1.68; 0.17	1.71; 0.17	1.53; 0.16	1.63; 0.17	1.76; 0.17	1.57; 0.16	1.70; 0.17	2.37; 0.27	2.15; 0.20	2.07; 0.26	2.29; 0.32	1.95; 0.23
ϕ_π^*	RoW Mon. Pol. (Inflation)	G (0.50, 0.25)	1.58; 0.17	1.59; 0.17	1.53; 0.20	1.61; 0.22	1.46; 0.15	1.06; 0.06	1.56; 0.17	1.48; 0.19	1.87; 0.24	1.52; 0.16	1.51; 0.15	1.88; 0.24
ϕ_y	US Mon. Pol. (GDP)	G (0.50, 0.25)	0.02; 0.01	0.03; 0.01	0.03; 0.02	0.02; 0.01	0.02; 0.01	0.01; 0.01	0.02; 0.01	0.07; 0.03	0.03; 0.02	0.04; 0.02	0.08; 0.04	0.05; 0.02
ϕ_y^*	RoW Mon. Pol. (GDP)	G (0.50, 0.25)	0.04; 0.02	0.04; 0.02	0.05; 0.03	0.13; 0.05	0.03; 0.01	0.02; 0.01	0.04; 0.02	0.01; 0.01	0.04; 0.02	0.02; 0.01	0.02; 0.02	0.05; 0.02
$\phi_{\Delta y}$	US Mon. Pol. (GDP change)	G (0.50, 0.25)	0.34; 0.04	0.33; 0.04	0.31; 0.05	0.37; 0.04	0.27; 0.04	0.41; 0.06	0.35; 0.04	0.26; 0.05	0.22; 0.04	0.30; 0.04	0.26; 0.04	0.33; 0.04
$\phi_{\Delta y}^*$	RoW Mon. Pol. (GDP change)	G (0.50, 0.25)	0.38; 0.05	0.38; 0.05	0.42; 0.07	0.26; 0.04	0.32; 0.05	0.35; 0.04	0.37; 0.05	0.17; 0.04	0.16; 0.04	0.25; 0.04	0.25; 0.04	0.34; 0.04
ρ_{MON}	US Interest Smoothing	B (0.50, 0.15)	0.74; 0.03	0.73; 0.03	0.68; 0.04	0.74; 0.03	0.75; 0.03	0.71; 0.04	0.75; 0.03	0.71; 0.04	0.70; 0.03	0.79; 0.03	0.83; 0.03	0.78; 0.03
ρ_{MON}^*	RoW Interest Smoothing	B (0.50, 0.15)	0.84; 0.02	0.83; 0.03	0.81; 0.03	0.88; 0.02	0.84; 0.02	0.79; 0.02	0.84; 0.02	0.75; 0.03	0.81; 0.03	0.84; 0.02	0.83; 0.03	0.87; 0.02
Ω	Import Adj. Cost	G (1.50, 0.75)	-	-	-	-	1.00; 0.44	-	-	-	-	-	-	-
ξ	Import-Intensity of BKK Spec.	B (0.50, 0.15)	-	-	-	-	-	-	-	-	-		0.01; 0.00	-

Note: G= Gamma, B= Beta, N= Normal distributions. P1= Mean and P2= Standard Deviation. Posterior moments are computed using 500000 draws from the distribution simulated by the Random Walk Metropolis algorithm. See Tables 4 and 5 for brief descriptions of all the model specifications.

Table 6 (Contd): Prior and Posterior Distributions of Shock Parameters

		PRIORS	POSTERIORS (Median; Standard Deviation) IN VARIOUS SPECIFICATIONS											
			Retaining Baseline Shocks						Altering the Choice of Shocks					
Symbol	Description	(P1, P2)	Baseline	Actual-TB	80-00	Complete	Import-Cost	BKK	PPP	B	B-IST	DSW-15%	DSW-1%	Risk-P
ρ_{TI}	AR(1) US Time Impatience	B (0.50, 0.15)	0.49; 0.14	0.48; 0.14	0.41; 0.14	0.57; 0.13	0.44; 0.14	0.62; 0.14	0.49; 0.14	0.83; 0.04	0.86; 0.03	0.81; 0.13	0.39; 0.13	-
ρ_{TI}^*	AR(1) RoW Time Impatience	B (0.50, 0.15)	0.82; 0.05	0.84; 0.05	0.76; 0.07	0.81; 0.11	0.81; 0.05	0.85; 0.04	0.82; 0.05	0.93; 0.02	0.91; 0.02	0.85; 0.04	0.86; 0.04	-
ρ_{INV}	AR(1) US Investment	B (0.50, 0.15)	0.71; 0.06	0.71; 0.06	0.67; 0.07	0.69; 0.06	0.76; 0.06	0.61; 0.07	0.72; 0.06	-	0.62; 0.05	0.69; 0.06	0.73; 0.06	0.74; 0.06
ρ_{INV}^*	AR(1) RoW Investment	B (0.50, 0.15)	0.66; 0.08	0.65; 0.08	0.47; 0.10	0.69; 0.06	0.71; 0.07	0.65; 0.09	0.68; 0.07	-	0.76; 0.06	0.79; 0.06	0.78; 0.07	0.62; 0.09
ρ_{UIP}	AR(1) UIP	B (0.50, 0.15)	0.86; 0.03	0.86; 0.03	0.84; 0.04	0.86; 0.03	0.83; 0.03	0.92; 0.02	0.87; 0.03	0.94; 0.02	0.90; 0.03	0.94; 0.02	0.94; 0.02	0.86; 0.03
ρ_{TFP}	AR(1) US TFP	B (0.50, 0.15)	0.92; 0.02	0.92; 0.02	0.86; 0.05	0.92; 0.03	0.94; 0.02	0.95; 0.01	0.92; 0.02	0.99; 0.00	0.99; 0.00	0.96; 0.01	0.93; 0.02	0.92; 0.02
ρ_{TFP}^*	AR(1) RoW TFP	B (0.50, 0.15)	0.98; 0.03	0.98; 0.02	0.92; 0.06	0.93; 0.04	0.95; 0.03	0.81; 0.05	0.97; 0.03	0.99; 0.00	0.99; 0.00	0.99; 0.01	0.96; 0.03	0.98; 0.02
ρ_{GOV}	AR(1) US Govt Spending	B (0.50, 0.15)	0.98; 0.01	0.97; 0.02	0.97; 0.02	0.98; 0.01	0.98; 0.01	0.99; 0.01	0.98; 0.01	-	-	0.99; 0.01	0.95; 0.03	0.97; 0.01
ρ_{GOV}^*	AR(1) RoW Govt Spending	B (0.50, 0.15)	0.97; 0.02	0.97; 0.02	0.96; 0.02	0.92; 0.03	0.95; 0.03	0.99; 0.01	0.97; 0.01	-	-	0.98; 0.02	0.94; 0.04	0.96; 0.02
ρ_{WM}	AR(1) US Wage	B (0.50, 0.15)	0.60; 0.10	0.62; 0.10	0.68; 0.10	0.61; 0.10	0.59; 0.10	0.52; 0.10	0.59; 0.10	-	-	0.54; 0.10	0.66; 0.10	0.62; 0.11
ρ_{WM}^*	AR(1) RoW Wage	B (0.50, 0.15)	0.92; 0.04	0.92; 0.04	0.88; 0.05	0.90; 0.05	0.91; 0.04	0.78; 0.13	0.92; 0.04	-	-	0.89; 0.07	0.89; 0.06	0.94; 0.03
ν_{WM}	MA(1) US Wage	B (0.50, 0.15)	0.46; 0.13	0.47; 0.13	0.48; 0.14	0.46; 0.13	0.44; 0.13	0.40; 0.12	0.45; 0.13	-	-	0.43; 0.12	0.48; 0.13	0.47; 0.13
ν_{WM}^*	MA(1) RoW Wage	B (0.50, 0.15)	0.80; 0.08	0.80; 0.08	0.75; 0.09	0.79; 0.09	0.81; 0.08	0.66; 0.15	0.80; 0.08	-	-	0.76; 0.10	0.73; 0.10	0.82; 0.07
ρ_M	AR(1) US Relative Import	B (0.50, 0.15)	-	-	-	-	-	-	-	1.00; 0.00	0.99; 0.00	-	-	-
ρ_X	AR(1) US Export Demand	B (0.50, 0.15)	-	-	-	-	-	-	-	-	-	0.99; 0.00	0.90; 0.03	-
ρ_{RP}	AR(1) US Risk Premium	B (0.50, 0.15)	-	-	-	-	-	-	-	-	-	-	-	0.45; 0.11
ρ_{RP}^*	AR(1) RoW Risk Premium	B (0.50, 0.15)	-	-	-	-	-	-	-	-	-	-	-	0.84; 0.04
$100\sigma_{TI}$	Inno. US Time Impatience	IG (0.1, 2)	0.17; 0.04	0.17; 0.04	0.20; 0.04	0.15; 0.04	0.18; 0.04	0.13; 0.04	0.17; 0.04	0.17; 0.04	0.10; 0.02	0.08; 0.05	0.20; 0.04	-
$100\sigma_{TI}^*$	Inno. RoW Time Impatience	IG (0.1, 2)	0.06; 0.02	0.06; 0.02	0.10; 0.03	0.08; 0.03	0.07; 0.02	0.05; 0.01	0.06; 0.02	0.04; 0.01	0.04; 0.01	0.05; 0.01	0.05; 0.02	-
$100\sigma_{INV}$	Inno. US Investment	IG (0.1, 2)	0.40; 0.05	0.40; 0.05	0.45; 0.07	0.42; 0.05	0.36; 0.05	0.51; 0.06	0.40; 0.05	-	0.56; 0.06	0.48; 0.05	0.48; 0.06	0.36; 0.05
$100\sigma_{INV}^*$	Inno. RoW Investment	IG (0.1, 2)	0.33; 0.05	0.33; 0.05	0.41; 0.06	0.32; 0.04	0.30; 0.04	0.35; 0.04	0.32; 0.04	-	0.35; 0.04	0.32; 0.04	0.34; 0.06	0.33; 0.05
$100\sigma_{UIP}$	Inno. UIP	IG (0.1, 2)	0.16; 0.03	0.16; 0.03	0.18; 0.04	0.17; 0.03	0.24; 0.05	0.07; 0.02	0.16; 0.03	0.08; 0.02	0.13; 0.03	0.16; 0.04	0.20; 0.06	0.18; 0.03
$100\sigma_{TFP}$	Inno. US TFP	IG (0.1, 2)	0.78; 0.19	0.78; 0.20	0.94; 0.30	0.87; 0.26	0.71; 0.19	0.80; 0.18	0.80; 0.20	1.07; 0.11	1.01; 0.09	0.55; 0.09	0.93; 0.31	0.80; 0.20
$100\sigma_{TFP}^*$	Inno. RoW TFP	IG (0.1, 2)	0.42; 0.05	0.42; 0.05	0.45; 0.06	0.43; 0.06	0.44; 0.06	0.47; 0.06	0.42; 0.05	1.17; 0.12	1.05; 0.10	0.51; 0.06	0.51; 0.08	0.43; 0.05
$100\sigma_{MON}$	Inno. US Mon. Pol.	IG (0.1, 2)	0.28; 0.03	0.28; 0.02	0.29; 0.03	0.29; 0.03	0.26; 0.02	0.32; 0.03	0.28; 0.03	0.28; 0.03	0.27; 0.02	0.25; 0.02	0.24; 0.02	0.26; 0.02
$100\sigma_{MON}^*$	Inno. RoW Mon. Pol.	IG (0.1, 2)	0.21; 0.03	0.21; 0.03	0.25; 0.04	0.17; 0.02	0.19; 0.02	0.21; 0.02	0.21; 0.03	0.23; 0.03	0.22; 0.03	0.18; 0.02	0.18; 0.02	0.20; 0.02
$100\sigma_{GOV}$	Inno. US Govt Spending	IG (0.1, 2)	0.43; 0.03	0.43; 0.03	0.45; 0.04	0.43; 0.03	0.43; 0.03	0.45; 0.03	0.43; 0.03	-	-	0.45; 0.03	0.46; 0.03	0.43; 0.03
$100\sigma_{GOV}^*$	Inno. RoW Govt Spending	IG (0.1, 2)	0.31; 0.02	0.31; 0.02	0.32; 0.03	0.31; 0.02	0.31; 0.02	0.31; 0.02	0.31; 0.02	-	-	0.32; 0.02	0.32; 0.02	0.31; 0.02
$100\sigma_{WM}$	Inno. US Wage	IG (0.1, 2)	0.13; 0.02	0.12; 0.02	0.13; 0.02	0.12; 0.02	0.13; 0.02	0.14; 0.02	0.13; 0.02	-	-	0.14; 0.02	0.12; 0.02	0.12; 0.02
$100\sigma_{WM}^*$	Inno. RoW Wage	IG (0.1, 2)	0.13; 0.02	0.13; 0.02	0.14; 0.02	0.13; 0.02	0.14; 0.02	0.16; 0.02	0.13; 0.02	-	-	0.15; 0.02	0.14; 0.02	0.13; 0.02
$100\sigma_{PPP}$	Inno. PPP	IG (0.1, 2)	3.04; 0.21	3.05; 0.22	3.03; 0.24	3.05; 0.21	3.12; 0.22	2.93; 0.21	-	-	-	-	-	3.05; 0.21
$100\sigma_M$	Inno. US Relative Import	IG (0.1, 2)	-	-	-	-	-	-	-	0.20; 0.02	0.19; 0.02	-	-	-
$100\sigma_X$	Inno. US Export Demand	IG (0.1, 2)	-	-	-	-	-	-	-	-	-	1.01; 0.08	4.83; 1.54	-
$100\sigma_{RP}$	Inno. US Risk Premium	IG (0.1, 2)	-	-	-	-	-	-	-	-	-	-	-	0.19; 0.03
$100\sigma_{RP}^*$	Inno. RoW Risk Premium	IG (0.1, 2)	-	-	-	-	-	-	-	-	-	-	-	0.07; 0.02

Chapter 3

Deep Habits, Nominal Rigidities and the Response of Consumption to Fiscal Expansions

Deep Habits, Nominal Rigidities and the Response of Consumption to Fiscal Expansions

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Abstract

Many empirical studies report that fiscal expansions have a positive effect on private consumption. This paper provides a closer examination of the 'deep' habits mechanism used by Ravn, Schmitt-Grohé and Uribe (2006) to generate the positive comovement between public and private consumption. In their set-up, habit-formation at the level of individual varieties makes the demand function facing the price-setting firm, dynamic. This makes it optimal for the firms to lower mark-ups of prices over nominal marginal costs when they expand production in response to the fiscal expansion, leading to an increase in the demand for labor and hence the real wage rises. The consequent intra-temporal substitution of consumption for leisure triggers the positive response of consumption. Here, we show that increasing either price or nominal wage stickiness, reduces the impact of fiscal spending shocks on the mark-up and the real wage. Hence, consumption is still *crowded out* as in traditional models.

JEL classification: E21, E31, E62.

Keywords: Deep Habits, Sticky Prices, Sticky Wages, Fiscal Shocks, Crowding-out.

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1 Introduction

The impact of cyclical fluctuations in government purchases on private consumption has received considerable attention in the structural vector autoregression literature. Using diverse schemes of identification, a large number of studies, *e.g.* Fatás and Mihov (2001), Blanchard and Perotti (2002), Bouakez and Rebei (2007), Galí, López-Salido and Vallés (2007) and Ravn, Schmitt-Grohé and Uribe (2006, 2007) report a rise in private consumption following a positive fiscal spending shock. The standard neoclassical model of macroeconomic fluctuations that emphasizes inter-temporally optimizing agents cannot generate this response. A rise in government spending generates, *ceteris paribus*, a concurrent increase in the present value of lumpsum taxes. This negative wealth effect induced by the fiscal expansion results in the lowering of private consumption, a phenomenon known in the literature as 'crowding-out'. The New Keynesian (NK) model that incorporates imperfect competition and nominal rigidities while retaining the traditional core of consumption-smoothing agents exhibits the same wealth effect that crowds out consumption after an expansionary fiscal shock. However, replicating the empirically relevant 'crowding-in' comovement within the traditional paradigm seems to have become less challenging, even if not yet comprehensively overcome, in recent theoretical models.[1]

A government spending shock financed by lumpsum taxes raises the agent's incentive to work and save more to offset the negative wealth effect. The surge in the supply of labor causes the real wage to fall. If one can induce the real wage to rise, the intra-temporal substitution of consumption for leisure may be strong enough to compensate for the unfavorable wealth effect. The recent theoretical literature offers two mechanisms that alter the dynamics of the real wage - generating a *rise* rather than allowing it to fall - to replicate the rise in consumption following the fiscal expansion.

Galí, López-Salido and Vallés (2007) use credit-constrained consumers who do not smooth consumption and simply consume their after-tax wage income. If prices are sticky and labor markets are imperfectly competitive, the real wage rises after the fiscal shock. Since the credit-constrained agent is insulated from the negative wealth-effect, the positive impact of the rise in the real wage raises her consumption. If the share of credit-constrained

[1] The positive response of consumption to fiscal expansions is not entirely undebated in the VAR literature. Peersman and Straub (2006) rely on signs derived from a New Keynesian model and find that consumption is significantly crowded out. In Mountford and Uhlig (2009), the movement in consumption is very gentle and insignificant.

agents is high enough, the positive response of aggregate consumption to the fiscal shock can be replicated. The macroeconomic effects of credit-constrained consumers have been widely studied in the literature.[2] However, the empirical plausibility of this mechanism to generate the rise in consumption has been questioned in an NK model estimated for the Euro Area by Coenen and Straub (2005), who find that the crowding-in of consumption is very mild and short-lived as the estimated share of credit-constrained agents is low.

In contrast, Ravn, Schmitt-Grohé and Uribe (henceforth RSU) (2006) propose an alternative mechanism to generate the positive response of private consumption, while adhering to the purely Ricardian consumption-smoothing environment.[3] They construct an economy where consumers form habits over individual goods that are produced by monopolistically competitive firms. The presence of *deep* habits - as opposed to the conventional 'superficial' habit-formation at the level of the aggregated good - induces falling mark-ups of prices over nominal marginal costs in response to a positive demand shock like a rise in public spending. As mark-ups are negatively linked to labor demand, hours worked rise in equilibrium enabling an increase in the real wage, thereby raising private consumption. However, unlike the extensive literature developed around the non-Ricardian framework adopted by Galí *et al.*, the efficacy of the deep habits mechanism in inducing the positive comovement between private and public consumption has not received much attention. This paper is a first attempt in that direction.[4]

The central result of our analysis is the finding that the crowding-in that RSU (2006) observe is contingent on their assumption that prices and wages are perfectly flexible. Starting from their original specification (and parameterization) with flexible prices and wages, we sequentially add higher degrees of nominal rigidities, first in prices and then

[2] See among many others, Bilbiie (forthcoming) and Erceg, Guerrieri and Gust (2005) for dynamic general equilibrium models with credit-constrained agents.

[3] Ravn, Schmitt-Grohé and Uribe (2007) use deep habits to generate the comovement in an open-economy setting.

[4] There are other more 'direct' ways of tackling the crowding-out issue in the inter-temporal model. Bouakez and Rebei (2007) introduce government spending as a complement to private consumption in the utility function. On the other hand, Linnemann and Schabert (2006) use government spending in the production function of the firm. Linnemann (2006) shows that the positive comovement can be achieved by using non-separable utility in a frictionless real business cycle model. However Bilbiie (forthcoming) observes that this is obtained by using a counter-intuitive downward sloping labor supply curve. Bilbiie also shows that under non-separable preferences, if consumption has to increase, even after the decrease in wealth, consumption has to be an inferior good. In this paper however, we restrict attention to the standard, *i.e.* unproductive and wasteful, fiscal shock and separable utility in the deep habits environment.

in wage adjustment. Simulations of the sticky-price-sticky-wage model suggest that the crowding-in comovement that the deep habits mechanism delivers is considerably weakened by the sluggish adjustment on the nominal side. In the presence of nominal rigidities, the mark-up and the real wage cease to move substantially in response to fiscal shocks and consequently consumption is still crowded out as in a standard NK or RBC model.

The rest of the paper is organized as follows. In Section 2, we introduce sticky prices and wages into the deep habits model of RSU (2006) while Section 3 presents the dynamic responses of key variables to study the effect of these nominal rigidities on the link between deep habits and the crowding-in of consumption by expansionary fiscal shocks. Section 4 draws the main conclusions. A detailed technical appendix documents the derivation of the main equations.

2 Nominal Rigidities in a Model with Deep Habits

The economic environment we consider departs from that of RSU (2006) only in the introduction of sticky prices and wages.[5] We focus on two segments of the model that are crucial to the link between the fiscal shock and the subsequent rise in consumption: deep habit formation by the public sector and the nominal rigidities facing the optimizing agents. In most instances, we proceed to the log-linearized versions of the equilibrium conditions without describing the non-linear versions. Steady-state variables are denoted by an upper bar and variables that are presented as deviations from the steady-state are denoted by '$\widehat{\ }$'.

Consumers The agent a aggregates a continuum of differentiated goods indexed by $i \in [0,1]$ for consumption C_{it}^{a} and investment I_{it}^{a} in the following way.

$$X_t^{C\,a} = \left[\int_0^1 \left(C_{it}^{a} - \theta^C S_{it-1}^{C} \right)^{\frac{\eta_P - 1}{\eta_P}} di \right]^{\frac{\eta_P}{\eta_P - 1}}, \; \theta^C \in [0,1), \; \eta_P > 1 \tag{1}$$

$$X_t^{I\,a} = \left[\int_0^1 \left(I_{it}^{a} - \theta^I S_{it-1}^{I} \right)^{\frac{\eta_P - 1}{\eta_P}} di \right]^{\frac{\eta_P}{\eta_P - 1}}, \; \theta^I \in [0,1) \tag{2}$$

[5] Ravn, Schmitt-Grohé, Uribe and Uusküla (2008) use a sticky-price deep habits model to study the effects of monetary policy. In contrast to this paper and that of RSU (2006), they abstract from investment and government spending.

where θ^C and θ^I indicate external habit formation at the level of the individual good. $S_i^{()}$ denotes the stock of habit and evolves as a weighted average of current consumption and investment and the predetermined stock of habit.

$$S_{it}^C = \omega^C S_{it-1}^C + \left(1 - \omega^C\right) C_{it},\ \omega^C \in [0, 1) \tag{3}$$

$$S_{it}^I = \omega^I S_{it-1}^I + \left(1 - \omega^I\right) I_{it},\ \omega^I \in [0, 1) \tag{4}$$

We assume deep habit formation in investment only for the symmetry of exposition. In our calibration exercises, investment habits are deactivated by imposing $\theta^I = \omega^I = 0$ to conform with the original RSU (2006) set-up.

Households derive utility from habit-adjusted consumption $X^{C\ a}$ while labor N^a gives disutility. We depart from RSU (2006) by assuming that the household provides differentiated labor services in the labor market at a nominal wage rate w^a. The household faces a labor demand schedule given by

$$N_t^a = \left(\frac{w_t^a}{W_t}\right)^{-\eta_W} N_t,\ \eta_W > 1$$

where N represents aggregate labor demand from the firm, W is the nominal wage index and η_W is the elasticity of substitution between varieties of labor. The household faces quadratic costs in adjusting their wages to given labor demand conditions. In real terms, these costs are given by

$$\frac{\Phi^W}{2}\left(\frac{w_t^a}{\bar{\pi}^{NW} w_{t-1}^a} - 1\right)^2 \frac{W_t N_t}{P_t} \tag{5}$$

It is costly for the household to deviate changes in its individual wage from steady-state nominal wage inflation $\bar{\pi}^{NW}$.[6] The cost function is specified in terms of the aggregate wage bill WN and the degree of wage stickiness is increasing in $\Phi^W \geqslant 0$. In addition to providing labor, agents rent out physical capital K^a to firms at a real net return of r^k. Physical capital depreciates at a constant rate δ per period. Agents have access to nominal bonds D^a that are available at a price $\frac{1}{R}$. The consumer is entitled to pure profits Π^a from the firm and also pays lumpsum taxes T^a to finance public expenditure. The optimization program that faces the generic consumer is given as

$$\max_{\substack{C_t^a,\ N_t^a,\ K_{t+1}^a,\\ X_t^{I\ a},\ D_{t+1}^a}} \mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(X_t^{C\ a}\right)^{1-\sigma_C}}{1-\sigma_C} - \frac{N_t^{a\ 1+\sigma_N}}{1+\sigma_N}\right],\ \sigma_C,\ \sigma_N \geqslant 0,\ \beta \in (0, 1)$$

[6] The cost function is similar to that used in Furlanetto (2007) except for the fact that we do not have to assume a zero steady-state nominal wage inflation.

subject to

$$\frac{\int_0^1 p_{it}\left(C_{it}^a + I_{it}^a\right) di}{P_t} + \frac{D_{t+1}^a}{R_t P_t} + T_t^a + \frac{\Phi^W}{2}\left(\frac{w_t^a}{\bar{\pi}^{NW} w_{t-1}^a} - 1\right)^2 \frac{W_t N_t}{P_t} = \frac{w_t^a}{P_t} N_t^a + r_t^k K_t^a + \frac{D_t^a}{P_t} + \Pi_t^a$$

$$X_t^{I\ a} + (1-\delta) K_t^a = K_{t+1}^a$$

where $\mathbf{E}_0$ indicates the expectational operator conditional on the information set available when the decision is made and $P_t \equiv \left(\int_0^1 p_{it}^{1-\eta_P} di\right)^{\frac{1}{1-\eta_P}}$ is an index over the prices for individual varieties.

First Order Necessary Conditions: We focus on conditions describing aggregate behavior in a symmetric equilibrium. The inter-temporal flow of aggregate habit-adjusted consumption is decided by the Euler equation.[7] Note that the Euler equation is identical to the one obtained from the conventional 'superficial' habit case.

$$\hat{X}_t^C = \mathbf{E}_t \hat{X}_{t+1}^C - \frac{1}{\sigma_C}\left(\hat{R}_t - \mathbf{E}_t \hat{\pi}_{t+1}\right) \text{ where } \hat{X}_t^C = \frac{\hat{C}_t}{1-\theta^C} - \frac{\theta^C}{1-\theta^C}\hat{S}_{t-1}^C \tag{6}$$

Optimal wage-setting implies that nominal wage inflation π^{NW} is positively related to the mark-up of the marginal rate of substitution between consumption and leisure over the real wage $\tilde{w}$.

$$\hat{\pi}_t^{NW} = \beta \mathbf{E}_t \hat{\pi}_{t+1}^{NW} + \frac{\eta_W - 1}{\Phi^W}\left(\sigma_N \hat{N}_t + \sigma_C \hat{X}_t^C - \hat{\tilde{w}}_t\right) \tag{7}$$

When $\Phi^W = 0$ as in RSU (2006), the wage mark-up is zero and the real wage is strictly tied down to the marginal rate of substitution between leisure and consumption.

$$\hat{\tilde{w}}_t = \sigma_N \hat{N}_t + \sigma_C \hat{X}_t^C \tag{8}$$

Government A key ingredient in achieving the positive response of consumption to the fiscal shock is the habit formation in the public sector. Similar to the private sector, government consumption is assumed to form *external* habits over the individual varieties. The public sector allocates spending over the individual goods G_i so as to maximize the quantity of a composite good.

$$X_t^G = \left[\int_0^1 \left(G_{it} - \theta^G S_{it-1}^G\right)^{\frac{\eta_P - 1}{\eta_P}} di\right]^{\frac{\eta_P}{\eta_P - 1}}, \ \theta^G \in [0,1)$$

[7] π is the inflation rate in the aggregate price level.

The stock of habit in the public sector evolves as

$$\omega^G S_{it-1}^G + \left(1-\omega^G\right) G_{it} = S_{it}^G,\ \omega^G \in [0,1)$$

Habit formation in the public sector may be motivated by the fact that the government forms procurement relationships that create a tendency to favor transactions with sellers who provided public goods in the past. The total demand for good i from the government is given by

$$G_{it} = \left(\frac{p_{it}}{P_t}\right)^{-\eta_P} X_t^G + \theta^G S_{it-1}^G$$

Observe that the presence of deep habits splits aggregate demand into two components. The first is price-elastic as given by $\left(\frac{p_{it}}{P_t}\right)^{-\eta_P} X_t^G$ and the second $\theta^G S_{it-1}^G$ is purely predetermined by habit formation. The presence of the price-inelastic habit term causes the *effective* price-elasticity of demand to be time-dependent. In a symmetric equilibrium, the price-elasticity of demand can be expressed in log-linearized terms as

$$\hat{\varepsilon}_{P,t}^G = \frac{\theta^G}{1-\theta^G}\left(\hat{G}_t - \hat{S}_{t-1}^G\right) \tag{9}$$

As we will see in the next subsection, the time-varying price-elasticity effect of habit formation has important implications for the price-setting behavior of the firm. The government operates under a simple fiscal rule with its expenditure fully financed by lumpsum taxes. Public consumption is modelled as pure waste and follows an AR(1) process.

$$\hat{G}_t = \rho \hat{G}_{t-1} + \epsilon_t,\ \epsilon_t \sim N(0, \sigma^G),\ \rho \in [0,1)$$

Firms The crux of the deep habits mechanism lies in the problem of the firm. The firm uses capital and labor in a Cobb-Douglas combination to produce its differentiated good. Analogous to the wage-setting problem of the consumer, we depart from RSU (2006) by introducing adjustment costs, specified *à la* Rotemberg (1982), into the firm's optimal pricing problem. It is costly for the firm to deviate changes in its individual price from steady-state inflation $\bar{\pi}$. The cost function is specified in terms of aggregate output and the degree of price stickiness is increasing in $\Phi^P > 0$. The firm maximizes the expected value of profits by choosing its price and quantities given its resource constraint, production technology, price adjustment cost, demand constraints and the evolution of the habit stocks.

$$\max_{\substack{p_{it},\,K_t,\,N_t\\ C_{it},\,I_{it},\,G_{it},\\ S^C_{it},\,S^I_{it},\,S^G_{it}}} \mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t U_{Ct} \begin{pmatrix} \frac{p_{it}}{P_t}\left(C_{it}+I_{it}+G_{it}\right) - r^k_t K_t - \tilde{w}_t N_t - \frac{\Phi^P}{2}\left(\frac{p_{it}}{\bar{\pi} p_{it-1}}-1\right)^2 Y_t \\ +mc_t\left(K^\alpha_t N^{1-\alpha}_t - fc - C_{it} - I_{it} - G_{it}\right) \\ +\nu_t{}^C\left(\left(\frac{p_{it}}{P_t}\right)^{-\eta_P} X^C_t + \theta^C S^C_{it-1} - C_{it}\right) \\ +\nu_t{}^I\left(\left(\frac{p_{it}}{P_t}\right)^{-\eta_P} X^I_t + \theta^I S^I_{it-1} - I_{it}\right) \\ +\nu_t{}^G\left(\left(\frac{p_{it}}{P_t}\right)^{-\eta_P} X^G_t + \theta^G S^G_{it-1} - G_{it}\right) \\ +\lambda_t{}^C\left(\omega^C S^C_{it-1} + \left(1-\omega^C\right)C_{it} - S^C_{it}\right) \\ +\lambda_t{}^I\left(\omega^I S^I_{it-1} + \left(1-\omega^I\right)I_{it} - S^I_{it}\right) \\ +\lambda_t{}^G\left(\omega^G S^G_{it-1} + \left(1-\omega^G\right)G_{it} - S^G_{it}\right) \end{pmatrix} \tag{10}$$

fc is the fixed cost in the firm's production technology required to ensure that profits are zero in steady state. mc, $\nu^{(\,)}$ and $\lambda^{(\,)}$ are respectively the Lagrange multipliers on the resource constraint, demand functions and the flow of the stock of habits. At the optimum, the multiplier mc on the resource constraint represents the real marginal cost.

The price-elasticity effect of deep habits is transmitted through the price-setting decision of the firm. The first order condition with respect to the price is given by

$$\beta\frac{U_{Ct+1}Y_{t+1}}{U_{Ct}Y_t}\Phi^P\frac{\pi_{t+1}}{\bar{\pi}}\left(\frac{\pi_{t+1}}{\bar{\pi}}-1\right) = \Phi^P\frac{\pi_t}{\bar{\pi}}\left(\frac{\pi_t}{\bar{\pi}}-1\right) + \eta_P\left[\frac{\nu^C_t X_t{}^C}{Y_t} + \frac{\nu^I_t X_t{}^I}{Y_t} + \frac{\nu^G_t X_t{}^G}{Y_t}\right] - 1 \tag{11}$$

Log-linearization gives us the Phillips curve that captures the contemporaneous impact of $\hat{\varepsilon}^{()}_P$, the time-varying elasticity of demand on the price level.

$$\begin{aligned} \hat{P}_t \;=\; & \frac{\beta}{1+\beta}\mathbf{E}_t\hat{P}_{t+1} + \frac{1}{1+\beta}\hat{P}_{t-1} - \frac{\eta_P\bar{\nu}^C\Xi_C\left(1-\theta^C\right)}{(1+\beta)\,\Phi^P}\left(\hat{\nu}^C_t + \hat{\varepsilon}^C_{P,t}\right) \\ & -\frac{\eta_P\bar{\nu}^I\Xi_I\left(1-\theta^I\right)}{(1+\beta)\,\Phi^P}\left(\hat{\nu}^I_t + \hat{\varepsilon}^I_{P,t}\right) - \frac{\eta_P\bar{\nu}^G\Xi_G\left(1-\theta^G\right)}{(1+\beta)\,\Phi^P}\left(\hat{\nu}^G_t + \hat{\varepsilon}^G_{P,t}\right) \\ & +\frac{1}{(1+\beta)\,\Phi^P}\left(\hat{Y}_t - \eta_P\bar{\nu}^C\Xi_C\left(1-\theta^C\right)\hat{C}_t - \eta_P\bar{\nu}^I\Xi_I\left(1-\theta^I\right)\hat{I}_t - \eta_P\bar{\nu}^G\Xi_G\left(1-\theta^G\right)\hat{G}_t\right) \end{aligned} \tag{12}$$

where Ξ_C, Ξ_I and Ξ_G are the steady-state shares of consumption, investment and government spending in output. As can be seen in Equation 9, a surge in aggregate demand such as the government spending shock induces a rise in the price elasticity. This makes it optimal for the firm to lower its price to maximize profits. However, it can easily be seen that from the Phillips curve that the presence of the price adjustment cost Φ^P weakens the effect of the elasticity on the price.[8]

The presence of deep habits exerts an additional effect on prices that emanates from the optimal choice of the quantities produced. The first order condition for satisfying demand from the public sector G_i is[9]

$$\frac{p_{it}}{P_t} - mc_t + \left(1 - \omega^G\right)\lambda_t^G = \nu_t^G \tag{13}$$

The Lagrange multiplier ν^G measures the incremental addition of a unit of public sector demand to the profits of the firm, *i.e.* it represents the real marginal profit.[10] At the optimum, this equals the sum of current profits $\frac{p_i}{P} - mc$ and the present value λ^G of having $1 - \omega^G$ additional units of demand in the next period. Imposing a symmetric equilibrium such that $p_i = P$ and using the fact that the real marginal cost is the inverse of the gross mark-up μ of price over nominal marginal cost, Equation 13 can be rewritten as

$$\frac{\mu_t - 1}{\mu_t} + \left(1 - \omega^G\right)\lambda_t^G = \nu_t^G \tag{14}$$

Since the stock of habit is persistent, the present value λ^G is determined by the first order condition with respect to S^G.

$$\lambda_t^G = \beta \mathbf{E}_t \frac{U_{Ct+1}}{U_{Ct}}\left(\theta^G \nu_{t+1}^G + \omega^G \lambda_{t+1}^G\right) \tag{15}$$

Combining the log-linearized versions of Equation 14 and Equation 15, we arrive at the dynamic flow of the mark-up.

$$\hat{P}_t - \widehat{NMC}_t = g_1 \hat{\nu}_t^G - \beta \mathbf{E}_t\left[g_2 \hat{\nu}_{t+1}^G + g_3\left(\hat{U}_{Ct+1} - \hat{U}_{Ct}\right)\right] + \beta g_4 \mathbf{E}_t\left(\hat{P}_{t+1} - \widehat{NMC}_{t+1}\right) \tag{16}$$

where g_1, g_2, g_3 and g_4 are combinations of the structural parameters.[11] Equation 16 determines the *intertemporal* effect of deep habits on prices. If the present discounted value

[8] In the Appendix, we demonstrate how the Eq.(12) reduces to the standard NK Phillips curve in the absence of deep habits.

[9] While we focus on demand from the public sector in this section, similiar equations also hold for consumption and investment.

[10] Note that the multiplier $\nu^{()}$ is not widely used outside the literature on deep habits. When the firm does not face a habit component in its demand function, *i.e.* $\theta^{()} = \varphi^{()} = 0$, the real marginal profit is negatively linked to the real marginal cost by the linear relation $\nu_t = \frac{p_{it}}{P_t} - mc_t$.

[11] See Appendix for the derivation. Note that we have expressed the mark-up as the difference between price and the nominal marginal cost.

of future profits is high due to the rise in demand that follows from the government spending shock, the firm has an incentive to lower the price. Equivalently, lowering prices in the present period ensures, due to the habit component in public sector demand, additional profits in the next period.

Pivotal to the positive effect of the fiscal expansion on private consumption is the role of the mark-up in the labor market. The first order condition with respect to the labor input of the firm is given as

$$\underbrace{\hat{\mu}_t}_{\hat{P}_t-\widehat{NMC}_t} + \widehat{\tilde{w}}_t = \hat{Y}_t - \hat{N}_t \tag{17}$$

When aggregate demand expands, the presence of the deep habits makes it optimal for the firm to lower prices and the mark-up when it increases output, generating a higher demand for labor via Equation 17. Given a fixed labor supply schedule, the real wage will rise increasing the permanent income of the agents. The increase in the real wage is the single most important factor that generates a rise in consumption in response to the fiscal expansion. On the other hand, a lowering of the mark-up also stimulates investment demand through the first order condition for physical capital.

$$\hat{\mu}_t + \hat{r}^k_t = \hat{Y}_t - \hat{K}_t \tag{18}$$

Goods Market Clearing Output is absorbed by consumption, investment and the government, each weighted by the respective great ratio.

$$\hat{Y}_t = \Xi_C \hat{C}_t + \Xi_I \hat{I}_t + \Xi_G \hat{G}_t \tag{19}$$

Monetary Authority The model is closed with the monetary authority following a simple rule as in Taylor (1993) to set the nominal interest rate in response to both inflation and output.[12]

$$\hat{R}_t = \phi_\pi \hat{\pi}_t + \phi_Y \hat{Y}_t \tag{20}$$

[12] As can be seen from Equation 16, a rise in the real interest rate will have a positive impact on current prices and mark-ups as the firm values future profits less. Hence, it may be instructive to consider the impact of various policy rules in the deep habits environment. We do not pursue this objective in this paper.

3 Simulation

3.1 Calibration

Table 1 displays all the parameter values that are used in the stochastic simulation of the model. The parameters that are common to the original model of RSU (2006) are given exactly the same values. We need some additional restrictions for the parameters governing the segment of the model that governs nominal rigidities. As in Taylor (1993), the elasticity of the interest rate to inflation ϕ_π is set at 1.5 while the analog for output ϕ_Y is set at 0.5. We also assume that elasticity between labor varieties is the same as that between the goods varieties at 5.3. We comment on the values assigned to Φ^P and Φ^W, the parameters governing nominal stickiness, in the next sub-section.

3.2 Impulse Response Analysis

We now examine the dynamics of key variables to an exogenous one per cent increase in government purchases. We first replicate the positive comovement between consumption and government spending obtained in the original paper using a variant of the model that uses flexible prices and wages. We then demonstrate how incomplete adjustment in either prices or wages nullifies this comovement.

Flexible Wages and Prices Figure 1 displays the dynamics of the model when we set $\Phi^P = \Phi^W = 0$, *i.e.* the flexible price and wage scenario of RSU (2006). To facilitate comparison with a world with standard superficial habits (at the level of the final good), we also plot the dynamic responses induced by the shock in a traditional sticky price NK model. The increase in government purchases exerts downward pressure on prices and mark-ups. The negative wealth effect of the increase in government purchases that lowers consumption and raises labor supply leading to a lowering of the real wage in standard models, continues to exist in the deep habits set-up. However, in this environment the government spending shock plays a role similar to that of a positive technology shock in standard models in that it induces a rise in labor *demand* via the falling mark-up seen in Equation 17. The increase in the demand for labor more than offsets the expansion in labor supply and this raises equilibrium hours worked and the real wage. In response, agents substitute consumption for leisure and consumption increases. Note that even though the mark-up and the real wage move quite strongly, the rise in consumption is very mild in magnitude, of the order of less than 0.02 percentage points in the medium- and long-term. The direction and magnitude of the dynamic responses of the mark-up, real wage and consumption are very similar to those exhibited in Figure 1, Panel 2 in RSU (2006).

Flexible Wages and Increasingly Sticky Prices We now consider an environment where the presence of adjustment costs makes it increasingly difficult for the firm to change prices to respond to movements in aggregate demand. Keeping all other parameters constant, we increase the price adjustment cost parameter Φ^P. The results are presented in Figure 1 along with the dynamics in the flexible price case. As a first step, we keep Φ^P at about 3 that corresponds to a price duration of about one quarter and a half.[13] One can already observe that even with mild price inflexibility, the dynamic responses of the mark-up, labor market variables and private consumption are muted compared to those obtained in the model with flexible prices. Interestingly, even though the real wage rises following the fall in the price and mark-up, the *nominal* wage declines and mimics the dynamic behaviour of the price level.

We now increase the price adjustment cost to that corresponding to about 1.75 quarters: the negative responses of the price level and the mark-up are more gentle. Labor demand and the real wage rise less while the fall in the nominal wage is weaker due to the relatively milder fall in prices. When the cost parameter is raised to about 8, *i.e.* a price duration of roughly two quarters, the mild downward movement in the mark-up stimulates the demand for labor less and hence the equilibrium real wage does not rise strongly. At this juncture, the contemporaneous impact multiplier on the real wage is about a quarter of a percentage point, which is about half the quantitative impact under flexible prices. This is clearly not enough to offset the negative wealth-effect of the government spending shock and consequently, consumption is still crowded out as in models without deep habits such as the NK model shown in the same figure.[14]

[13] In the Appendix, we illustrate the point that for a given degree of price stickiness, the presence of the habit component in the price-setting equation, decreases the elasticity of inflation to real marginal costs. This implies that the interpretation of the price-stickiness in 'quarterly' terms is one based on the traditional forward-looking NKPC under Rotemberg costs, that can easily be compared to the Calvo-contract analog which has a direct time-scale interpretation. On the other hand, the wage-setting Equation 7 can be compared to its Calvo equivalent in a straightforward manner.

[14] Price stickiness in the NK model is calibrated at $\Phi_P = 8$ as in the final experiment in the deep habits case.

Mildly Sticky Prices and Increasingly Sticky Wages Intuitively, since the deep habits mechanism relies considerably on the rise in the real wage and the consequent intratemporal substitution effect to raise consumption, a very likely candidate to negate the positive comovement between public and private consumption is nominal wage rigidity. In Figure 2, we exhibit the dynamic responses for the case in which we set the price adjustment cost parameter Φ^P at a value consistent with price changes every one and a half quarters while systematically increasing the wage adjustment cost parameter Φ^W to those corresponding to two, three and four quarters respectively. In the same figure, we also reproduce the responses in the flexible wage case explored in the previous subsection. Since price stickiness is now fixed, the source of inertia in the mark-up is the nominal marginal cost that in turn is dominated by the wage component. Clearly, with increasing wage adjustment costs, the counter-cyclical movement in the mark-up decreases. At a three quarter nominal wage duration, consumption is very mildly crowded out by the fiscal shock, but consequently the rise in the real wage is just enough to allow the intratemporal substitution effect to balance the negative wealth effect of the fiscal expansion and hence the consumption response is almost zero for more than three years, before the latter effect is dominant and crowding-out occurs. However, at a four quarter wage duration, the real wage movement is not strong enough to overwhelm the negative wealth effect and consumption is crowded out by the fiscal shock on impact and remains below trend persistently. Hence, even when prices are relatively flexible, the deep habits mechanism is unable to generate the positive comovement when the rigidity in wage adjustment gets stronger.

4 Conclusion

This paper provides a closer examination of the nexus between deep habits, counter-cyclical mark-ups and the crowding-in of private consumption as a result of increases in purchases by the public sector as documented by Ravn, Schmitt-Grohé and Uribe (2006). We find that the positive comovement between public and private consumption observed in the original deep habits environment is contingent on the assumption that prices and wages are perfectly flexible. When nominal adjustment is sluggish either in prices or wages, the counter-cyclical movement that the government spending shock induces in the mark-up is milder and hence consumption is still *crowded out* as in traditional RBC and NK models.

In another context, Coenen and Straub (2005) report in an estimated DSGE model that including credit-constrained agents is insufficient to generate the positive response of consumption in the NK set-up due to both a small share of such agents and due to the presence of wage rigidities that mutes the effect of the falling mark-up on the real wage and hence the consumption by the credit-constrained agent. Unlike Coenen and Straub, our computational experiments suggest that even with perfect labor markets, the deep habits mechanism ceases to generate a rise in the real wage necessary to overcome the negative wealth effect of government spending shocks in the presence of increasing price stickiness. Naturally, for a mechanism that relies heavily on the rise in the real wage and the intra-temporal substitution effect to generate crowding-in, the link between the mark-up and the real wage is further weakened by the presence of nominal wage stickiness, as we saw in subsequent experiments. Even when price-stickiness is quite mild, increasing nominal wage rigidity by itself induces the crowding-out of consumption under deep habits.

A natural extension of this research agenda would be to test empirically the ability of the deep habits approach *vis-à-vis* its alternatives in generating the crowding-in co-movement. Quite unlike in the environments featuring deep habits or credit-constrained agents where government spending is pure waste, there exist other models in the literature that allow a more elaborate role for government spending in the economy by making it complementary to private consumption in the utility function (Bouakez and Rebei 2007) or by making it augment the firm's production function (Linnemann and Schabert 2006). Embedding the various frictions in a DSGE model estimated with likelihood-based methods and culling out the specification the data favors most would considerably enrich our understanding of the fiscal transmission mechanism. We leave this exercise for future research.

A Appendix

In this section, we derive some of the key equations used in the main text. We refer the reader to the main text for the notation. For the equations that hold for all three components of aggregate demand - consumption, investment and government - we indicate the concerned variable with Z and parameters specific to the particular component of demand are superscripted with Z. A more detailed exposition of the derivations is available on request.

A.1 Deep Habits: The Basics

A.1.1 Demand Function

This subsection draws heavily from Ravn, Schmitt-Grohé and Uribe (2004). The standard problem to obtain the demand functions (aggregated over all consumers) of each individual good is

$$\max_{Z_{it}} P_t X_t^Z - \int_0^1 P_{it}\left(Z_{it} - \theta^Z S_{it-1}^Z\right) di$$

subject to

$$X_t^Z = \left[\int_0^1 \left(Z_{it} - \theta^Z S_{it-1}^Z\right)^{\frac{\eta_P - 1}{\eta_P}} di\right]^{\frac{\eta_P}{\eta_P - 1}} \quad \forall Z \in \{C,\ I,\ G\}$$

The resultant demand function for the individual good is

$$Z_{it} = \left(\frac{p_{it}}{P_t}\right)^{-\eta_P} X_t^Z + \theta^Z S_{it-1}^Z \tag{A1}$$

The presence of the price-inelastic habitual term causes the *effective* price elasticity of demand to be time-dependent. In particular

$$\varepsilon_{P,t}^Z = \frac{\partial\left[\left(\frac{p_{it}}{P_t}\right)^{-\eta_P} X_t^Z + \theta^Z S_{it-1}^Z\right]}{Z_{it}} \frac{p_{it}}{\partial p_{it}} = -\eta_P\left(1 - \theta^Z \frac{S_{it-1}^Z}{Z_{it}}\right)$$

This is unlike in models where the demand function that faces the firm has no habitual component, *i.e.* $\theta^Z = 0$, so that the price elasticity of demand is constant at $-\eta_P$. We can express the time-varying price elasticity of demand in log-linearized terms.

$$\hat{\varepsilon}_{P,t}^Z = \frac{\theta^Z}{1-\theta^Z}\left(\hat{Z}_t - \hat{S}_{t-1}^Z\right) \ \forall Z \in \{C,\ I,\ G\}$$

Log-linearization of Equation A1 yields,

$$X_t^Z = \frac{\hat{Z}_t}{1-\theta^Z} - \frac{\theta^Z}{1-\theta^Z}\hat{S}_{t-1}^Z \ \forall Z \in \{C,\ I,\ G\} \tag{A2}$$

A.1.2 Selected Steady-State Conditions

We list a few steady-state conditions that will facilitate the log-linearization of the equations determining the price-elasticity and inter-temporal effects of deep habits. In steady-state, the first order conditions for the firm's choice of quantities, *i.e.* Equation 14 and

Equation 15 are given by

$$\frac{\bar{\mu}_{DH}-1}{\bar{\mu}_{DH}}+\left(1-\omega^{Z}\right)\bar{\lambda}^{Z}=\bar{\nu}^{Z}\ \forall Z\in\{C,\ I,\ G\} \tag{ss-i}$$

and

$$\bar{\lambda}^{Z}=\frac{\beta\theta^{Z}}{1-\beta\omega^{Z}}\bar{\nu}^{Z}\ \forall Z\in\{C,\ I,\ G\} \tag{ss-ii}$$

Combining steady-state conditions ss-i and ss-ii, we get

$$\frac{\bar{\mu}_{DH}-1}{\bar{\mu}_{DH}}\left[\frac{1-\beta\omega^{Z}}{1-\beta\omega^{Z}-\beta\theta^{Z}\left(1-\omega^{Z}\right)}\right]=\bar{\nu}^{Z}\ \forall Z\in\{C,\ I,\ G\} \tag{ss-iii}$$

Steady-State Mark-Up Note that

1. There are no price adjustment costs in steady-state: $\Phi_{P}=0$.
2. Aggregate demands are given by : $\bar{X}^{Z}=\bar{Z}\left(1-\theta^{Z}\right)\ \forall Z\in\{C,\ I,\ G\}$
3. The great ratios are defined as : $\Xi_{Z}=\frac{\bar{Z}}{\bar{Y}}\ \forall Z\in\{C,\ I,\ G\}$

Impose these conditions on the price-setting condition Equation 11 in steady-state to get

$$\eta_{P}=\frac{1}{\Xi_{C}\left(1-\theta^{C}\right)\bar{\nu}^{C}+\Xi_{I}\left(1-\theta^{I}\right)\bar{\nu}^{I}+\Xi_{G}\left(1-\theta^{G}\right)\bar{\nu}^{G}} \tag{ss-iv}$$

Use steady-state condition ss-iii to substitute out the steady-state values of the Lagrange multipliers $\bar{\nu}^{Z}$

$$\eta_{P}=\frac{1}{\frac{\bar{\mu}_{DH}-1}{\bar{\mu}_{DH}}\left[\Xi_{C}\left\{\frac{\left(1-\theta^{C}\right)\left(1-\beta\omega^{C}\right)}{1-\beta\omega^{C}-\beta\theta^{C}\left(1-\omega^{C}\right)}\right\}+\Xi_{I}\left\{\frac{\left(1-\theta^{I}\right)\left(1-\beta\omega^{I}\right)}{1-\beta\omega^{I}-\beta\theta^{I}\left(1-\omega^{I}\right)}\right\}+\Xi_{G}\left\{\frac{\left(1-\theta^{G}\right)\left(1-\beta\omega^{G}\right)}{1-\beta\omega^{G}-\beta\theta^{G}\left(1-\omega^{G}\right)}\right\}\right]}$$

This expression yields the gross steady-state mark-up $\bar{\mu}_{DH}$:

$$\bar{\mu}_{DH}=\frac{\eta_{P}\Gamma}{\eta_{P}\Gamma-1} \tag{ss-v}$$

where $\Gamma\equiv\left\{\begin{array}{l}\Xi_{C}\left\{\frac{\left(1-\theta^{C}\right)\left(1-\beta\omega^{C}\right)}{1-\beta\omega^{C}-\beta\theta^{C}\left(1-\omega^{C}\right)}\right\}+\Xi_{I}\left\{\frac{\left(1-\theta^{I}\right)\left(1-\beta\omega^{I}\right)}{1-\beta\omega^{I}-\beta\theta^{I}\left(1-\omega^{I}\right)}\right\}+\Xi_{G}\left\{\frac{\left(1-\theta^{G}\right)\left(1-\beta\omega^{G}\right)}{1-\beta\omega^{G}-\beta\theta^{G}\left(1-\omega^{G}\right)}\right\}<1\\ 1\text{ in the absence of deep habits } i.e.\ \theta^{Z}=\omega^{Z}=0\end{array}\right\}$

A.2 The Flow of Value from the Stock of Habit

In the log-linearization of Equation 15, we use steady-state condition ss-ii and simplify to get

$$\hat{\lambda}_t^{\,Z} = \left(1-\beta\omega^Z\right)\mathbf{E}_t\hat{\nu}_{t+1}^Z + \beta\omega^Z\mathbf{E}_t\hat{\lambda}_{t+1}^Z + \mathbf{E}_t\left(\hat{U}_{Ct+1}-\hat{U}_{Ct}\right)\ \forall Z\in\{C,\ I,\ G\} \qquad \text{(A3)}$$

A.3 Inter-temporal Mark-Up Dynamics

Steady-state conditions ss-ii and ss-iii are helpful in the log-linearization of the condition for the optimal choice of the quantities to satiate demand, namely Equation 14. The log-linearized version is given by

$$\hat{\lambda}_t^{\,Z} = \frac{1-\beta\omega^Z}{\beta\theta^Z\left(1-\omega^Z\right)}\hat{\nu}_t^Z - \frac{1-\beta\omega^Z-\beta\theta^Z\left(1-\omega^Z\right)}{\beta\theta^Z\left(1-\omega^Z\right)\left(\bar{\mu}_{DH}-1\right)}\hat{\mu}_t$$

Substitute this expression into Equation A3 and simplify to get the dynamics of the mark-up. For $z\in\{c,\ i,\ g\}$

$$\begin{aligned}\hat{\mu}_t \;=\;& \underbrace{\frac{\left(\bar{\mu}_{DH}-1\right)\left(1-\beta\omega^Z\right)}{1-\beta\omega^Z-\beta\theta^Z\left(1-\omega^Z\right)}}_{z_1}\hat{\nu}_t^Z - \underbrace{\frac{\left(\bar{\mu}_{DH}-1\right)\left(1-\beta\omega^Z\right)\left[\theta^Z\left(1-\omega^Z\right)+\omega^Z\right]}{1-\beta\omega^Z-\beta\theta^Z\left(1-\omega^Z\right)}}_{z_2}\beta\mathbf{E}_t\hat{\nu}_{t+1}^Z \\ & -\underbrace{\frac{\theta^Z\left(\bar{\mu}_{DH}-1\right)\left(1-\omega^Z\right)}{1-\beta\omega^Z-\beta\theta^Z\left(1-\omega^Z\right)}}_{z_3}\beta\mathbf{E}_t\left(\hat{U}_{Ct+1}-\hat{U}_{Ct}\right) + \beta\underbrace{\omega^Z}_{z_4}\mathbf{E}_t\hat{\mu}_{t+1} \qquad \text{(A4)}\end{aligned}$$

In the main text, we use the public sector analog of the above equation and also express the mark-up as the difference between price and nominal marginal cost.

A.4 The Phillips Curve

Log-linearizing, the first order condition with respect to the price level Equation 11, we get the Phillips curve

$$\begin{aligned}\hat{\pi}_t \;=\;& \beta\mathbf{E}_t\hat{\pi}_{t+1} \\ & -\frac{\eta_P}{\Phi_P}\left[\begin{array}{l}\bar{\nu}^C\Xi_C\left(1-\theta^C\right)\left(\hat{\nu}_t^C+\hat{X}_t^C-\hat{Y}_t\right)+\bar{\nu}^I\Xi_I\left(1-\theta^I\right)\left(\hat{\nu}_t^I+\hat{X}_t^I-\hat{Y}_t\right)\\ +\bar{\nu}^G\Xi_G\left(1-\theta^G\right)\left(\hat{\nu}_t^G+\hat{X}_t^G-\hat{Y}_t\right)\end{array}\right]\end{aligned}$$

Now, we proceed in three steps to obtain the Phillips curve used in the main text:

1. Substitute out the aggregate demands $\hat{X}_t^Z = \frac{Z_t}{1-\theta^Z} - \frac{\theta^Z}{1-\theta^Z}\hat{S}_{t-1}^Z \; \forall Z \in \{C,\ I,\ G\}$

2. To introduce the time-varying price elasticities of demand $\hat{\varepsilon}_{P,t}^Z = \frac{\theta^Z}{1-\theta^Z}\left(\hat{Z}_t - \hat{S}_{t-1}^Z\right)$ in the Phillips curve, we add and subtract $\frac{\theta^C}{1-\theta^C}\hat{C}_t$, $\frac{\theta^I}{1-\theta^I}\hat{I}_t$ and $\frac{\theta^G}{1-\theta^G}\hat{G}_t$ in the respective parentheses

Use $\eta_P = \frac{1}{\Xi_C\left(1-\theta^C\right)\bar{\nu}^C + \Xi_I\left(1-\theta^I\right)\bar{\nu}^I + \Xi_G\left(1-\theta^G\right)\bar{\nu}^G}$ on the coefficient on output and collect output and the demand terms together in the square brackets.

$$\begin{aligned}\hat{\pi}_t \;=\; & \beta \mathbf{E}_t \hat{\pi}_{t+1} + \frac{1}{\Phi_P}\left[\hat{Y}_t - \eta_P \bar{\nu}^C \Xi_C \left(1-\theta^C\right)\hat{C}_t - \eta_P \bar{\nu}^I \Xi_I \left(1-\theta^I\right)\hat{I}_t - \eta_P \bar{\nu}^G \Xi_G \left(1-\theta^G\right)\hat{G}_t\right] \\ & -\frac{\eta_P \bar{\nu}^C \Xi_C \left(1-\theta^C\right)}{\Phi_P}\left(\hat{\nu}_t^C + \hat{\varepsilon}_{P,t}^C\right) - \frac{\eta_P \bar{\nu}^I \Xi_I \left(1-\theta^I\right)}{\Phi_P}\left(\hat{\nu}_t^I + \hat{\varepsilon}_{P,t}^I\right) \\ & -\frac{\eta_P \bar{\nu}^G \Xi_G \left(1-\theta^G\right)}{\Phi_P}\left(\hat{\nu}_t^G + \hat{\varepsilon}_{P,t}^G\right)\end{aligned} \tag{A5}$$

In the main text, we have expressed this equation in terms of prices rather than inflation to highlight the negative impact of the rising elasticity of demand on the price level.

Linking the Deep Habits Phillips Curve to the Standard NKPC To derive the standard NK Phillips curve from the deep habits Phillips curve, we use the following conditions.

1. Deep habits do not prevail in any component of aggregate demand: $\theta^Z = \omega^Z = 0 \; \forall \; Z \in \{C,\ I,\ G\}$

2. From the analogs for steady-state conditions ss-iii, ss-iv and ss-v, we get $\frac{\bar{\mu}_{DH}-1}{\bar{\mu}_{DH}} = \bar{\nu}^Z = \frac{1}{\eta_P} \Leftrightarrow \bar{\mu}_{DH} = \frac{\eta_P}{\eta_P - 1}$. The mark-up is now exactly the same as in standard models of monopolistic competition.

3. Using the two above conditions in Equation A4, we obtain a negative relationship between real marginal costs and real marginal profits: $-\left(\eta_P - 1\right)\widehat{mc}_t = \hat{\nu}_t^Z$.

4. The price elasticities in log-linearized terms are zero when there are no deep habits: $\hat{\varepsilon}_{P,t}^Z = 0$.

5. Markets clear : $\hat{Y}_t = \Xi_C \hat{C}_t + \Xi_I \hat{I}_t + \Xi_G \hat{G}_t$ and the great ratios add up to unity: $\Xi_C + \Xi_I + \Xi_G = 1$.

Using the aforementioned expressions in the deep habits Phillips curve, Equation A5, we recover the standard New Keynesian Phillips Curve under Rotemberg adjustment costs.

$$\hat{\pi}_t = \beta \mathbf{E}_t \hat{\pi}_{t+1} + \frac{\eta_{_P} - 1}{\Phi_P} \widehat{mc}_t \tag{A6}$$

Interpreting Rotemberg Adjustment Costs on a Calvo 'Price Duration' Scale Let us consider the simplest case when consumption is the only component of aggregate demand $\Xi_C = 1$ while $\Xi_I = \Xi_G = 0$ and when the stock of habit is not persistent, *i.e.* $\omega^C = 0$.

We restate Equation A4 that decides the mark-up dynamics and express it in terms of the real marginal profit. We will also use the fact the mark-up is the negative of the real marginal cost.

$$\hat{\nu}_t^C = -\frac{1 - \beta\theta^C}{\bar{\mu}_{DH} - 1} \widehat{mc}_t + \theta^C \beta \mathbf{E}_t \left[\hat{\nu}_{t+1}^C + \beta \mathbf{E}_t \left(\hat{U}_{Ct+1} - \hat{U}_{Ct} \right) \right]$$

Plug the above equation into the deep habits Phillips curve Equation A5, use the analogs for steady-state conditions ss-iii, ss-iv and ss-iv when consumption is the only component of demand and rearrange variables to get

$$\hat{\pi}_t = \beta \mathbf{E}_t \hat{\pi}_{t+1} + \left[\frac{\eta_{_P} - 1}{\Phi_P} + \frac{\theta^C \left(\beta - \eta_{_P} \right)}{\Phi_P} \right] \widehat{mc}_t - \frac{\theta^C \beta}{\Phi_P} \mathbf{E}_t \left[\hat{\nu}_{t+1}^C + \mathbf{E}_t \left(\hat{U}_{Ct+1} - \hat{U}_{Ct} \right) \right] - \frac{\hat{\varepsilon}_{P,t}^C}{\Phi_P} \tag{A7}$$

As seen in Equation A6, in a world without deep habits, the Rotemberg adjustment scheme delivers a coefficient $\frac{\eta_{_P}-1}{\Phi_P}$ on the marginal cost in the NKPC. In the Calvo analog where the slope coefficient is $\frac{(1-\beta\xi)(1-\xi)}{\xi}$ such that $\frac{1}{1-\xi}$ determines the duration of price stickiness. In the standard case, it is possible to compare slope coefficients on the marginal costs given by both schemes of price adjustment, to interpret the Rotemberg cost in price duration terms. But the presence of deep habits complicates matters. In the above Phillips curve, Equation A7, the coefficient on marginal costs will be *less* than the conventional $\frac{\eta_{_P}-1}{\Phi_P}$ as long as $\eta_{_P} > \beta$, a condition satisfied in our calibration where $\eta_{_P} = 5.3$ and $\beta = 0.9902$. Thus for a given value of adjustment costs, the introduction of deep habits reduces the response of prices to the marginal cost and hence it is impossible to compare the deep habits Phillips curve slopes to the Calvo analog. Hence we stick to the standard forward-looking NKPC to interpret the slope of the Phillips curve in 'quarterly' terms. Of course, in the wage-setting equation, the slope under Rotemberg costs can be easily interpreted on the Calvo scale.

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Table 1: Calibration

SYMBOL	DESCRIPTION	VALUE	
Parameters in Flexible Price and Wage Model as in RSU (2006)			
σ_C	Risk Aversion	2	
β	Subjective Discount Factor	0.9902	
$1/\sigma_N$	Frisch Elasticity	1.3	
η_P	Elasticity of Substitution between Goods Varieties	5.3	
$\theta^C = \theta^G$	External Habit in Consumption and Government Spending	0.86	
$\chi^C = \chi^G$	Persistence of Habit Stock in Consumption and Government Spending	0.85	
θ^I	External Habit in Investment	0	
χ^I	Persistence of Habit Stock in Investment	0	
α	Share of Capital in Production Function	1/4	
Ξ_G	Steady-state Share of Government in GDP	0.12	
Ξ_C	Steady-state Share of Consumption in GDP	0.70	
ρ	Persistence of Government Spending Shock	0.90	
σ^G	Standard Deviation of Shock	1%	
Additional Parameters in Models with Nominal Rigidities			
ϕ_π	Interest Rate Response to Inflation	1.50	
ϕ_Y	Interest Rate Response to Output	0.50	
Φ^P, Φ^W	Price and Wage Adjustment Costs	Value	Calvo Contract Duration (NKPC Scale)
		2.85	~ 1.50 Q
		5.60	~ 1.75 Q
		8.52	~ 2.00 Q
		25.29	~ 3.00 Q
		50.17	~ 4.00 Q

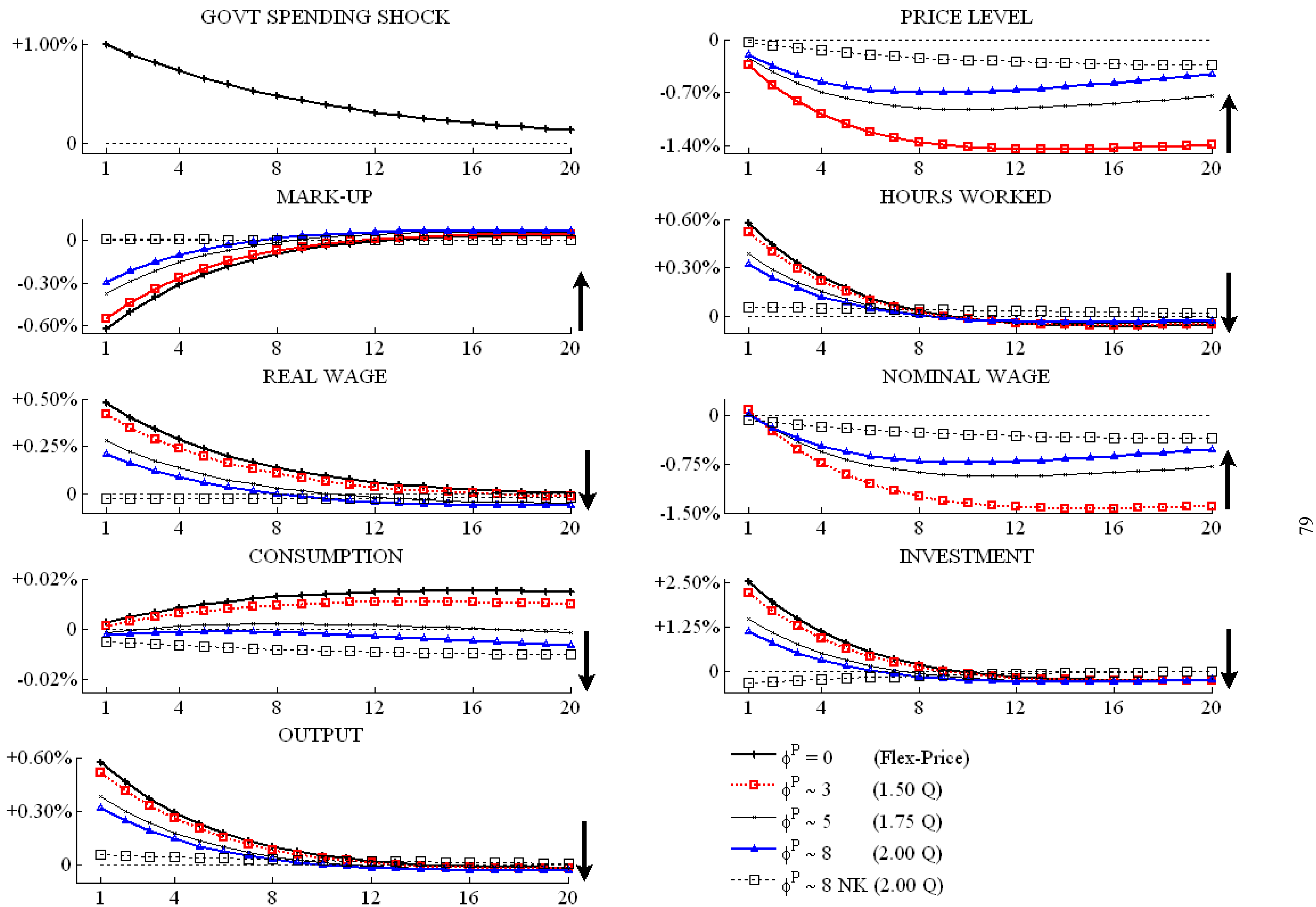

Figure 1: Dynamic Responses to a Government Spending Shock in the Deep Habits Model under Increasing Price Stickiness when Nominal Wages are Flexible

Note: The quarterly interpretation of the adjustment cost parameter is based on a standard NKPC obtained under a Calvo pricing scheme.

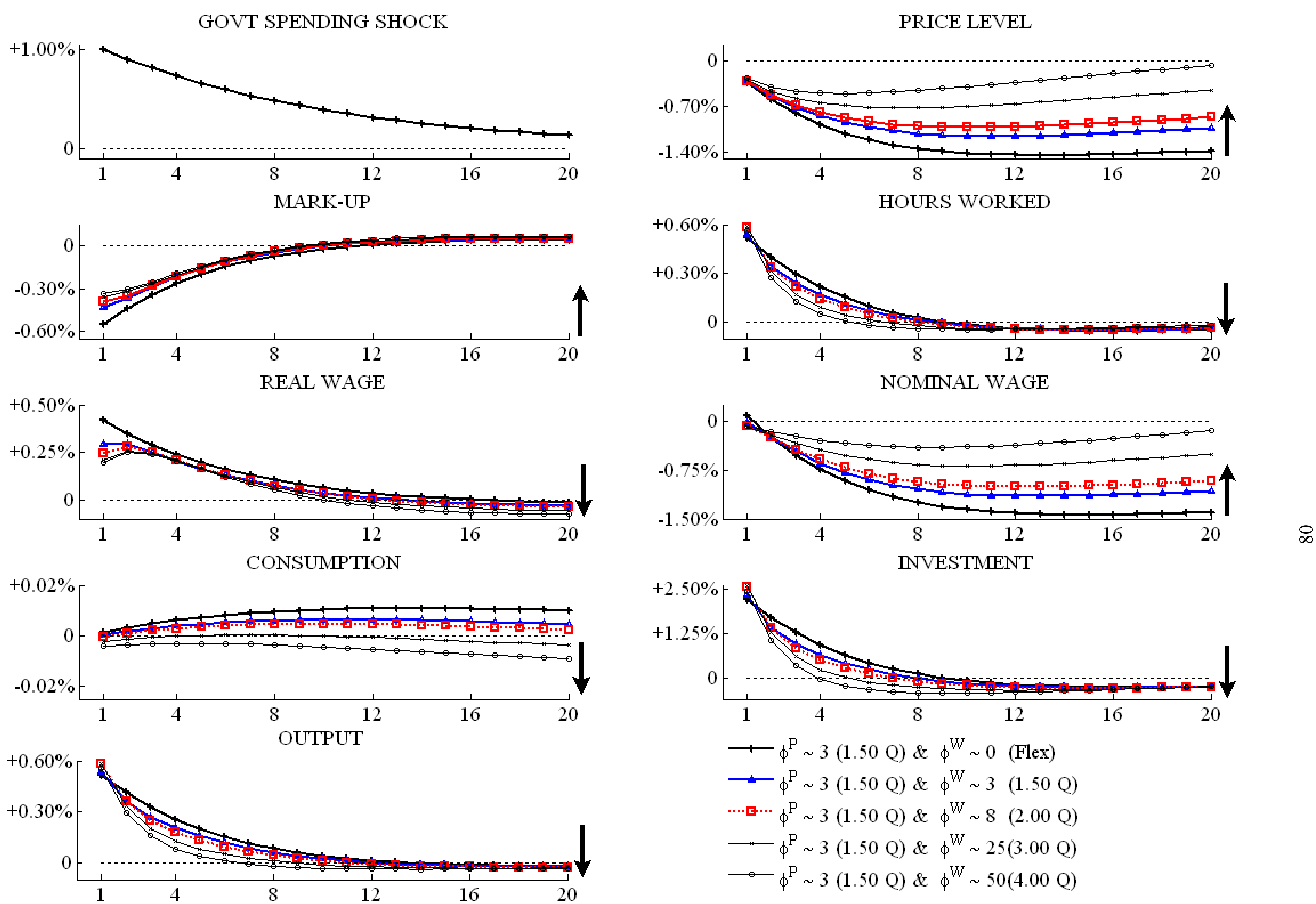

Figure 2: Dynamic Responses to a Government Spending Shock in the Deep Habits Model under Mild Price Stickiness and Increasing Nominal Wage Stickiness

Note: The quarterly interpretation of the adjustment cost parameter is based on a standard NKPC obtained under a Calvo pricing scheme.

Chapter 4

Disaggregating Real Exchange Rate Dynamics: A Structural Approach

Dissaggregating Real Exchange Rate Dynamics: A Structural Approach

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Abstract

This paper employs a small open economy DSGE model, estimated over 1986-2009, to decompose the dynamic influence of domestic and international prices on the Canada-US real exchange rate. While the real exchange rate mimics the dynamic behavior of the relative price of non-tradables in terms of tradables in response to a non-tradable sector-specific disturbance, the purely tradable component dominates in the case of other shocks, irrespective of their structural origin. Variance decompositions reveal that the sources of the movements in the tradable component lie in unsystematic deviations from uncovered interest parity as well as import price mark-up shocks. Consequently, these disturbances are far more potent than internal tradable or non-tradable sector-specific disturbances in driving real exchange rate fluctuations.

JEL classification: C11, F41

Keywords: New Open Economy Macroeconomics, Non-Tradables, Real Exchange Rate, Bayesian Inference, DSGE Estimation.

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1 Introduction

The profession has generally struggled to relate the persistent and volatile behavior of the real exchange rate to macroeconomic fundamentals. Key to understanding the real exchange rate are its multiple constituents: the nominal exchange rate as well as the domestic and international relative prices. Traditional theorists viewed the movements in the real exchange rate as shifts in the relative price of non-tradable goods to that of tradable goods (Samuelson 1964). However, more recently, economists have appealed to the price of tradable goods, *i.e.* deviations from the law of one price in particular, to explain real exchange rate movements (See *e.g.* Betts and Devereux 2000). This paper makes an empirical contribution to this classic debate.

Extant empirical analyses of the nexus between the real exchange rate and relative prices have relied on a statistical decomposition of the in-sample volatility of the real exchange rate into that of its various components. Engel (1999) decomposes the variance of the CPI-based US real exchange rate *vis-à-vis* many of its trade-partners and observes that almost none of the variability emanates from the relative price of non-tradables. Chari, Kehoe and McGrattan (2002) attribute as much as 98 percent of the variance of the Euro-Dollar real exchange rate to the international relative price of tradables. These reduced-form results have motivated a generation of general equilibrium models of the exchange rate, *e.g.* Chari, Kehoe and McGrattan (2002), to abstract from non-tradables. More recently, Wolden Bache, Næss and Sveen (2009) explicitly introduce export and import prices into the definition of the real exchange rate and find that the wedge between these prices at the border and the price of domestically tradable goods, *i.e.* deviations from the law of one price, contribute between 30 and 70 percent of the variance of four US bilateral real exchange rates while the non-tradable component always contributes below 10 percent.

However, recent empirical studies have provided evidence in favor of the importance of the relative price of non-tradable goods for the real exchange rate. Burstein, Eichenbaum and Rebelo (2006) find that the non-traded component accounts for about half the variability of the real exchange rate. Betts and Kehoe (2008), in an extensive study of 50 economies over 25 years, attribute a third of the variance of the real exchange rate to the relative price of non-tradables. These results suggest that the open economy literature, more specifically the empirical general equilibrium models that study the important sources of exchange rate fluctuations (*e.g.* Lubik and Schorfheide 2005, Bergin 2006 and Rabanal and Tuesta 2009), may have been premature in abandoning fully articulated non-tradable sectors.

In the light of the inconclusive evidence provided by the reduced-form literature, we offer a structural treatment of real exchange rate fluctuations, by embedding the exchange rate in a richly specified dynamic stochastic general equilibrium (DSGE) model that allows it to fluctuate in response to deviations from the law of one price as well as changes in the relative price of non-tradables. Subsequently, we use full-information methods to fit the DSGE model on time series on a battery of domestic and international price series that constitute the real exchange rate. The central contribution of this paper is a study of the correspondence between the real exchange rate and its constituent relative prices in dynamic responses to structural shocks. Complementary to the reduced-form studies, we recover the dominant relative price effect, but unlike that literature, we distinguish between the movements that are generated in the relative prices, and hence the aggregate real exchange rate due to the distinct structural origin of these disturbances.[1]

Our results are in the direction of those reported by Engel (1999) and Wolden Bache *et al.* (2009). In all the variants of the estimated DSGE model, we find that while the real exchange rate inherits the dynamic behavior of the internal relative price of non-tradables in response to a technology shock specific to the non-tradable sector, movements in the purely tradable component dictate real exchange rate dynamics in the case of other disturbances, irrespective of their structural origin. Not surprisingly, sector-specific disturbances hardly matter in the larger scheme: the shock to the uncovered interest parity condition, that exerts its influence via the purely tradable component, accounts for about half the variability whenever it is used in the estimation exercise. In fact, even when we do not employ this shock in the estimation, internal sector-specific shocks do not matter for the forecast variance. Price mark-up shocks in the import segment of the model appear to be more potent than shocks to internal prices in generating fluctuations in the real exchange rate.

The model that we build and estimate is in the new tradition of open economy models

[1] It is important to understand that we examine the impulse responses and the forecast variance of the real exchange rate while the statistical studies decompose the variance of the real exchange rate into the variances and covariances of its defined components, typically the international relative price of tradables and the internal relative price of non-tradables.

estimated with Bayesian methods as seen in Justiniano and Preston (2006), Jacob and Peersman (2008) and Rabanal and Tuesta (2009). Unlike these models, in view of our objective, we introduce a non-tradable sector in our DSGE model as in two empirical papers which study real exchange rate dynamics in stylized two-country models linking the US and the Euro-Area. Rabanal and Tuesta (2007) and Cristadaro, Gerali, Neri and Pisani (2008) evaluate the ability of standard empirical open economy models, augmented with non-tradables, to address fundamental macroeconomic puzzles as the real exchange rate volatility and persistence anomaly and the consumption real-exchange rate anomaly, together with understanding the important stochastic driving forces of the real exchange rate.[2]

Rabanal and Tuesta (2007) find that technology shocks in the non-tradable sector determine a third of the conditional forecast variance of the Euro-Dollar real exchange rate. However, their results rest uncomfortably on two unrealistic features of the economic environment they construct: the imposition of strict uncovered interest parity and the law of one price for tradable goods. The first feature - the presence of the parity condition that ties down the expected evolution of the nominal exchange rate to the interest differential - obscures the fact that the exchange rate is mostly driven by stochastic deviations from uncovered interest parity, as the vast majority of the empirical open economy literature finds (See *e.g.* Rabanal and Tuesta 2009 and Justiniano and Preston 2006). On the other hand, under the law of one price, export and import prices are simply foreign currency equivalents of the price of the domestic tradable good and there is perfect passthrough of exchange rate fluctuations into import prices. This strategy precludes the use of export and import prices, which are typically more volatile than domestic prices, in the estimation of their model and hences ignores the possibility of these prices acting as potential sources of volatility for the real exchange rate as reported by Wolden Bache *et al.* (2009). The second study closely related to ours is that of Cristadoro, Gerali, Neri and Pisani (2008) who impose neither pure uncovered interest parity nor the law of one price in their empirical model. In extreme contrast to Rabanal and Tuesta (2007), they find that about ninety percent of the asymptotic forecast variance of fluctuations in the Euro-Dollar exchange rate are driven by deviations from interest parity. However, just as Rabanal and Tuesta (2007), they continue to ignore import and export price series in their empirical analysis.

[2] Recent theoretical models that use non-tradable goods to address exchange rate puzzles include Benigno and Thoenissen (2008), Dotsey and Duarte (2008) and Corsetti, Dedola and Leduc (2008).

While our DSGE model shares the introduction of a non-tradable sector with both papers, and uses endogenous deviations from the law of one price as in Cristadoro *et al.* (2008), the focus on the inter-linkages between the relative prices distinguishes this paper from its precedents. Furthermore, instead of studying the synthetic Euro-Dollar series in a stylized two-country model as in the two aforementioned papers, we examine the Canada-US real exchange rate in a small open economy (SOE) model. This modelling strategy delivers a statistical advantage: unlike Rabanal and Tuesta (2007) and Cristadoro *et al.* (2008), all the prices that can influence the real exchange rate, *i.e.* the prices of domestic tradable and non-tradable goods, foreign price level as well as bilateral variables as the nominal exchange rate and export and import prices, can be treated as observable states in the estimation while preserving the tractability of the exercise.[3] We can also allow for a much richer specification of the home economy, Canada in our case, while the larger and relatively closed foreign economy that forms the second country, the US, is modelled in a minimalist way. We fit the SOE model on twelve macroeconomic quarterly time series over 1986-2009.

To the extent that the SOE model is estimated with Canada-US data, this paper is also related to the work of Justiniano and Preston (2006, 2010) and Dib (2003) who estimate more stylized SOE models on similar datasets. The former examines the influence of foreign shocks on the SOE while the latter compares macroeconomic dynamics under closed economy and open economy assumptions. In contrast to the focus of this paper, these studies do not dwell on the components of the real exchange rate. In this manner, we contribute simultaneously to two strands of the literature, the modern empirical general equilibrium open economy literature as well as the reduced-form literature on the influence of relative prices on the exchange rate.

We proceed as follows. Section 2 outlines a SOE model that endogenously determines the international and internal prices that constitute the real exchange rate. Section 3 details the disaggregation of the real exchange rate and discusses the qualitative differences in the influences of its component prices. Section 4 presents the estimation results while Section 5 evaluates the robustness of the main results. Section 6 concludes.

[3] While Rabanal and Tuesta (2007) only use aggregate CPI and PPI (domestic tradables) series, Cristadoro *et al.* (2008) use the goods as well as services components of the CPI. As empirical two-country models typically employ an equal number of series for each economy along with bilateral series as the exchange rate, both studies ignore the export-import price series as well as physical investment to preserve tractability.

2 The Baseline Small Open Economy Model

The baseline model has much in common with the closed economy models estimated for the US and the Euro-Area by Smets and Wouters (2003, 2007). The open economy dimension of the model is very similar to that of Adolfson *et al.* (2007) who estimate a rich SOE model for Sweden. All these models have enjoyed considerable success in terms of statistical fit. We only present equilibrium conditions for the SOE that are log-linearized around a simple symmetric non-stochastic steady-state with balanced trade and no inflation or exchange rate depreciation. Variables presented as logarithmic deviations from the steady-state are denoted by a superscript '$\frown$'. Typically, foreign economy variables and parameters are denoted with a superscript ' * '. We follow Smets and Wouters (2003) in abstracting from balanced growth and normalizing all the shocks in the theoretical model so that they enter the estimation with a unit coefficient. The structural innovations in all the AR(1) shock processes, η^x are *i.i.d.* $N(0, \sigma_x)$ and the autocorrelation coefficients are indicated by $\rho_x \in [0, 1)\ \forall x$.

Aggregation Sectors Production takes place in three layers in the SOE. The bottom layer is composed of two monopolistically competititive sectors producing the non-tradable bundle Y^{NT} and the home-produced tradable bundle Y_H^T. The middle layer is formed by a perfectly competitive sector that aggregates the home-produced tradable bundle and the imported bundle Y_M^T to compose a final tradable good Y^T in a CES combination, very similar to the Armington aggregation of home and imported tradables seen in Backus, Kydland and Kehoe (1994). ξ_M denotes the share of imports in the final tradable aggregate. The top layer is constituted by a perfectly competitive sector that combines the non-tradable bundle and the tradable aggregate again in a CES composite to form the final good Y for consumption and investment. ξ_{NT} denotes the share of non-tradable component absorbed by the SOE. The final consumption-investment good is not traded internationally.

The aggregate price level P^{CPI}, *i.e.* the consumer price index, is a convex combination of price of the non-tradable bundle P^{NT} and that of the final tradable aggregate P^T. On the other hand, the price level of the tradable aggregate combines the price of the domestic tradable bundle P_H^T and the price of the imported bundle P_M^T.

$$\hat{P}_t^{CPI} = (1 - \xi_{NT})\hat{P}_t^T + \xi_{NT}\hat{P}_t^{NT} \tag{1}$$

$$\hat{P}_t^T = (1 - \xi_M)\hat{P}_{Ht}^T + \xi_M \hat{P}_{Mt}^T \tag{2}$$

$\mu_{NT} > 0$ denotes the elasticity of substitution between the non-tradable bundle and the tradable aggregate and $\mu_M > 0$ denotes the trade elasticity. These parameters moderate the relationship between the relative prices and the corresponding quantities through the demand functions for the aggregated intermediate bundles.

$$\hat{Y}_t^T = \hat{Y}_t + \mu_{NT}\xi_{NT}\left(\hat{P}_t^{NT} - \hat{P}_{Ht}^T\right) \tag{3}$$

$$\hat{Y}_t^{NT} = \hat{Y}_t^T - \mu_{NT}\left(\hat{P}_t^{NT} - \hat{P}_{Ht}^T\right) \tag{4}$$

$$\hat{Y}_{Ht}^T = \hat{Y}_t^T + \mu_M\xi_M\left(\hat{P}_{Mt}^T - \hat{P}_{Ht}^T\right) \tag{5}$$

$$\hat{Y}_{Mt}^T = \hat{Y}_{Ht}^T - \mu_M\left(\hat{P}_{Mt}^T - \hat{P}_{Ht}^T\right) \tag{6}$$

To be sure, there are numerous ways of introducing non-tradables into a DSGE model. For example, in their theoretical model Dotsey and Duarte (2008) devise an intricate input-output structure where non-tradable final output enters two segments of the model, unlike in our case. Firstly, it is used as an input to produce the final tradable aggregate, which is partly used for investment while the remaining enters the final consumption bundle. Secondly, non-tradables are also a direct input in the consumption bundle to form the final good.[4] Given our objective to estimate the model, the simple production-based structure that we employ is less restrictive on the data as it economizes on the model-implied steady-state shares (*e.g.* ξ_M, ξ_{NT}) which are typically calibrated. This is in contrast to a richer specification which allows for different shares of non-tradables and imports in consumption and investment and entails a multiplicity of share parameters that have to be fixed.[5] An additional advantage of this simple specification lies in the tradable segment as we avoid making a distinction between consumption and investment

[4] In another theoretical study, Benigno and Thoenissen (2008), the final good which has a non-tradable component, is only used for consumption. The intermediate non-tradable and tradable goods firms that own the capital stocks use a proportion of their output as investment in their production process in the next period. On the other hand, in the empirical literature, Rabanal and Tuesta (2007) use only a final consumption bundle that combines tradable and non-tradable components. The output of both intermediate sectors that is not consumed is absorbed by fiscal spending shocks. In Cristadoro *et al.* (2008) non-tradables appear both in the form of distribution services and are part of the final composite for consumption. Unlike the theorists, the latter two studies abstract from investment.

[5] As DSGE models are usually estimated with demeaned data, the filtered data is not informative about these long-run share parameters and most empirical modellers prefer to calibrate these shares from sample averages.

export-import prices. Empirically, this is useful as the export-import price data that we use to estimate the model cover a wide variety of investment as well as consumption goods ranging over agricultural products, machinery, oil and automobiles. On the downside, the simplicity of the structure necessitates abstracting from distribution services, a form of expenditure on the non-tradable sector found to be important to understand real exchange rate behavior in theoretical models, *e.g.* Corsetti and Dedola and Leduc (2008).[6]

Intermediate Sectors The two intermediate goods sectors in the SOE are monopolistically competitive, with the aggregated non-tradable and tradable bundles being Dixit-Stiglitz composites of a continuum of differentiated intermediate varieties. Each intermediate variety can be both consumed and invested and the distinction between varieties between the two sectors lies only in the tradability. In each sector indexed by $z \in \{T,\ NT\}$, output is produced by a Cobb-Douglas function that combines labor and capital rented from the household, with α governing the share of capital. ε^z is an AR(1) sector-specific productivity disturbance and fc is a fixed cost in production necessary to ensure that profits are zero in steady-state.

$$y_t^z = fc\left(\alpha \hat{K}_{t-1}^z + (1-\alpha)\hat{N}_t^z + \varepsilon_t^z\right) \tag{7}$$

The factors of production are perfectly mobile and hence their respective prices, the (CPI-based) real rates r^k and w are equalized across sectors. This implies the real marginal costs $(1-\alpha)\hat{w} + \alpha\hat{r}^k - \varepsilon^z$ are identical, except for the sector-specific technological disturbances.

Nominal adjustment is imperfect in both sectors and price-setting behavior is governed by Calvo lotteries. $\theta^{NT} \in (0,1)$ is the Calvo probability parameter for the sales of non-tradables while $\iota^{NT} \in [0,1]$ denotes the degree of price indexation. If $\beta \in (0,1)$ denotes the agent's subjective discount factor and $\mathbf{E}_t$ is the expectational operator conditional on the information set at the beginning of period t, the Phillips curve for sales by the

[6] The presence of distribution services combined with a very low elasticity of substitution between home-produced tradables and imports, can be used to generate high real exchange rate volatility and low-passthrough. However, Rabanal and Tuesta (2007) report that the presence of this friction reduces the empirical fit of their Euro-Area-US model considerably.

non-tradable sector is given by

$$\hat{\pi}_t^{NT} = \frac{\iota^{NT}}{1+\beta\iota^{NT}}\hat{\pi}_{t-1}^{NT} + \frac{\beta}{1+\beta\iota^{NT}}\mathbf{E}_t\hat{\pi}_{t+1}^{NT} + \frac{\left(1-\beta\theta^{NT}\right)\left(1-\theta^{NT}\right)}{\theta^{NT}\left(1+\beta\iota^{NT}\right)}\left[\left(1-\alpha\right)\hat{w}_t + \alpha\hat{r}_t^k - \varepsilon_t^{NT} + \hat{P}_t^{CPI} - \hat{P}_t^{NT}\right] \tag{8}$$

On the other hand, $\theta_H^T \in (0,1)$ is the Calvo parameter for domestic sales of the tradable good while $\iota_H^T \in [0,1]$ denotes the degree of price indexation for domestic sales. The Phillips curve for domestic sales is given by

$$\hat{\pi}_{Ht}^T = \frac{\iota_H^T}{1+\beta\iota_H^T}\hat{\pi}_{Ht-1}^T + \frac{\beta}{1+\beta\iota_H^T}\mathbf{E}_t\hat{\pi}_{Ht+1}^T + \frac{\left(1-\beta\theta_H^T\right)\left(1-\theta_H^T\right)}{\theta_H^T\left(1+\beta\iota_H^T\right)}\left[\left(1-\alpha\right)\hat{w}_t + \alpha\hat{r}_t^k - \varepsilon_t^T + \hat{P}_t^{CPI} - \hat{P}_{Ht}^T\right] \tag{9}$$

The international trade structure of the SOE is adapted from Adolfson *et al.* (2007). The monopolistic importer buys foreign output at the domestic currency equivalent of the aggregate foreign price level P^{CPI*} and sells it in the SOE in the local currency as a mark-up over the procurement price, generating a wedge between the import price facing the final good sector and the cost of imports. This wedge expressed as $\hat{P}^{CPI*} + \widehat{NEx} - \hat{P}_M$ can be interpreted, as in Lubik and Schorfheide (2005), as the law of one price gap. If $\theta_M^T \in (0,1)$ is the Calvo parameter for import sales and $\iota_M^T \in [0,1]$ denotes the degree of price indexation, the imports Phillips curve is given by

$$\hat{\pi}_{Mt}^T = \frac{\iota_M^T}{1+\beta\iota_M^T}\hat{\pi}_{Mt}^T + \frac{\beta}{1+\beta\iota_M^T}\mathbf{E}_t\hat{\pi}_{Mt}^T + \frac{\left(1-\beta\theta_M^T\right)\left(1-\theta_M^T\right)}{\theta_M^T\left(1+\beta\iota_M^T\right)}\left[\hat{P}_t^{CPI*} + \widehat{NEx}_t - \hat{P}_{Mt} + \varepsilon_{Mt}^{PM}\right] \tag{10}$$

The presence of price-stickiness dampens the transmission of fluctuations in the nominal exchange rate NEx (a rise in which implies a depreciation of the SOE currency) into import prices and hence the aggregate price level of the SOE. ε_M^{PM} is an AR(1) cost-push shock to import price inflation and can be motivated by time-varying demand elasticities facing the importer in the SOE. In effect, it acts the exogenous component of the law of one price gap.

Export sales of the SOE constitute only an infinitesimal proportion of total absorption in the foreign economy. Y^* and P^{CPI*} indicate foreign output and consumer price levels, the demand function for exports is given by

$$\hat{Y}_{Ht}^{*T} = \hat{Y}_t^* - \mu_M\left(\hat{P}_{Ht}^{*T} - \hat{P}_t^{CPI*}\right) \tag{11}$$

Analagous to the importer, the representative exporter sets his price P_{Ht}^{*T} in the foreign currency as a mark-up over its nominal marginal cost, the price of the home-produced tradable good. If $\theta_H^{*T} \in (0,1)$ is the Calvo parameter for export sales and $\iota_H^{*T} \in [0,1]$ denotes the degree of price indexation, the corresponding Phillips curve is given by

$$\hat{\pi}_{Ht}^{*T} = \frac{\iota_H^{*T}}{1+\beta\iota_H^{*T}}\hat{\pi}_{Ht-1}^{*T} + \frac{\beta}{1+\beta\iota_H^{*T}}\mathbf{E}_t\hat{\pi}_{Ht+1}^{*T} + \frac{\left(1-\beta\theta_H^{*T}\right)\left(1-\theta_H^{*T}\right)}{\theta_H^{*T}\left(1+\beta\iota_H^{*T}\right)}\left[\hat{P}_{Ht}^{T} - \widehat{NEx}_t - \hat{P}_{Ht}^{*T} + \varepsilon_{Ht}^{*PM}\right] \tag{12}$$

where ε_{Ht}^{*PM} is a cost-push shock to export price inflation and as in the importer's case, it can be motivated by time-varying demand elasticities facing the exporter in the foreign market.

Consumers Consumers have access to private risk-free nominal one-period bonds that are denominated either in domestic or foreign currency and the domestic physical capital stock to facilitate the inter-temporal transfer of wealth. Equation 13 determines the flow of consumption that is indicated by C. The curvature parameter $\sigma_C > 0$ and the external habit coefficient $\vartheta \in [0,1)$ govern the inter-temporal elasticity of substitution. R is the gross interest rate on domestic bonds set by the monetary authority while π^{CPI} is the gross inflation in the consumer price index. ε^{TI} is a disturbance that can be interpreted as a 'time-impatience' shock to the subjective discount factor and evolves as AR(1) process.

$$\hat{C}_t = \frac{1}{1+\vartheta}\mathbf{E}_t\hat{C}_{t+1} + \frac{\vartheta}{1+\vartheta}\hat{C}_{t-1} - \frac{1}{\sigma_C}\frac{(1-\vartheta)}{(1+\vartheta)}\left(\hat{R}_t - \mathbf{E}_t\hat{\pi}_{t+1}^{CPI}\right) + \varepsilon_t^{TI} \tag{13}$$

Equation 14 presents uncovered interest parity (UIP), the arbitrage condition for home and foreign bonds that pins down the expected depreciation of the domestic currency to the differential in nominal interest rates. Since the failure of UIP in its primitive form has been well documented, we add to this condition an AR(1) stochastic process ε^{UIP}. Devereux and Engel (2002) attribute this random deviation from strict interest parity as a source of exchange rate disconnect from fundamentals and interpret it as emanating from misaligned expectations from foreign currency traders on the evolution of the currency. Farrant and Peersman (2006) present vector autoregression evidence on the importance of 'pure exchange rate' shocks in driving OECD exchange rates. In a DSGE environment, a pure exchange rate shock can easily be understood as a disturbance to the interest parity condition. When we estimate the model, the UIP shock captures the persistence in the nominal exchange rate data that we cannot match in its absence given that interest parity predicts that the exchange rate behaves in a purely forward-looking manner. Finally, due to the incomplete asset markets set-up, $\kappa > 0$ that measures the cost incurred by SOE investors in acquiring net foreign assets NFA, is used as a stationarity-inducing device.[7]

$$\mathbf{E}_t\widehat{NEx}_{t+1} - \widehat{NEx}_t = \hat{R}_t - \left(\hat{R}_t^* - \kappa\widehat{NFA}_t + \varepsilon_t^{UIP}\right) \tag{14}$$

The consumer invests a quantity I of the final good in the aggregate capital stock K that is rented out to both the non-tradable and tradable sectors as factor inputs. Investment is subject to adjustment costs increasing in the parameter $\psi > 0$ that delays its response to changes in its marginal value measured by Tobin's Q.

$$\hat{I}_t = \frac{\beta}{1+\beta}\mathbf{E}_t\hat{I}_{t+1} + \frac{1}{1+\beta}\hat{I}_{t-1} + \frac{1}{\psi(1+\beta)}\widehat{TQ}_t + \varepsilon_t^{INV} \tag{15}$$

$$\hat{K}_t = \delta\hat{I}_t + (1-\delta)\hat{K}_{t-1} + \delta\psi(1+\beta)\varepsilon_t^{INV} \tag{16}$$

$$\widehat{TQ}_t = (1-\beta(1-\delta))\mathbf{E}_t\hat{r}_{t+1}^k + \beta(1-\delta)\mathbf{E}_t\widehat{TQ}_{t+1} - \left(\hat{R}_t - \mathbf{E}_t\hat{\pi}_{t+1}^{CPI}\right) \tag{17}$$

ε^{INV} is an AR(1) investment-specific technology shifter that increases the marginal efficiency of the conversion of investment into the capital stock. Equation 17 is the first order condition for the capital stock that decides the dynamics of Tobin's Q.

The wage is set as in Smets and Wouters (2003). The agent provides a differentiated labor service in the factor market and has monopoly power. If $\theta_W \in (0,1)$ is the Calvo parameter for nominal wage stickiness, $\sigma_N \geqslant 0$ is the reciprocal of the Frisch elasticity of labor and $\chi_W > 1$ is the elasticity of substitution between labor varieties, nominal wage inflation is given by

$$\hat{\pi}_t^{NW} - \iota_W\hat{\pi}_{t-1}^{CPI} = \beta\mathbf{E}_t\left(\hat{\pi}_{t+1}^{NW} - \iota_W\hat{\pi}_t^{CPI}\right) - \frac{(1-\beta\theta_W)(1-\theta_W)}{\theta_W(1+\sigma_N\chi_W)}\left[\hat{w}_t - \sigma_N\hat{N}_t - \sigma_C\frac{\hat{C}_t - \vartheta\hat{C}_{t-1}}{1-\vartheta}\right] + \varepsilon_t^{WM} \tag{18}$$

The degree of indexation of wages to lagged CPI inflation is measured by $\iota_W \in [0,1]$. ε^{WM} is a cost-push disturbance that can be interpreted as a shock to the mark-up of the real wage over the marginal rate of substitution between consumption and leisure (in square brackets) and as in Smets and Wouters (2007) follows an ARMA $(1,1)$ process defined as $\varepsilon_t^{WM} = \rho_{WM}\,\varepsilon_{t-1}^{WM} + \eta_t^{WM} - \nu_{WM}\eta_{t-1}^{WM}$ such that $\nu_{WM} \in [0,1)$.

[7] See Bergin (2006) and the references cited therein for alternative solutions to the unit-root problem in incomplete financial asset markets models.

Market Clearing Final goods market-clearing requires that the production of the final good sector is absorbed by consumption, investment and government spending, each weighted by its respective steady-state share in output.

$$\hat{Y}_t = \Xi_C \hat{C}_t + \Xi_I \hat{I}_t + \Xi_G \hat{G}_t \tag{19}$$

The unmodelled fiscal sector is financed by lumpsum taxes and consumes a fixed proportion of output.

The intermediate tradable goods are sold both at home and exported.

$$\hat{y}_t^T = (1 - \xi_M) \hat{Y}_{Ht}^T + \xi_M \hat{Y}_{Ht}^{*T} \tag{20}$$

The factor markets clear when the supply of labor and capital by the household is absorbed by demand from both the non-tradable and tradable sectors. $\varkappa_N$ and $\varkappa_K$ are the shares of labor and capital demand by the non-tradable sector in the aggregate demand for the respective factor of production.

$$\hat{N}_t = \varkappa_N \hat{N}_t^{NT} + (1 - \varkappa_N) \hat{N}_t^T \tag{21}$$

$$\hat{K}_t = \varkappa_K \hat{K}_t^{NT} + (1 - \varkappa_K) \hat{K}_t^T \tag{22}$$

The inter-temporal flow of net foreign assets as a proportion of tradable output is given by

$$\widehat{NFA}_t - \frac{1}{\beta} \widehat{NFA}_{t-1} = \xi_M \left(\widehat{NEx}_t + \hat{P}_{Ht}^{*T} + \hat{Y}_{Ht}^{*T} \right) - \xi_M \left(\hat{P}_{Mt}^T + \hat{Y}_{Mt}^T \right) \tag{23}$$

Monetary Authority The monetary authority in the SOE follows a simple empirical Taylor-type rule to set the nominal interest rate, targetting CPI inflation and the level as well as changes in output.

$$\hat{R}_t = \rho_{MON} \hat{R}_{t-1} + (1 - \rho_{MON}) \left(\phi_\pi \hat{\pi}_t^{CPI} + \phi_y \hat{Y}_t \right) + \phi_{\Delta y} \left(\hat{Y}_t - \hat{Y}_{t-1} \right) + \eta_t^{MON} \tag{24}$$

Foreign Economy The model is closed by postulating that the foreign economy follows a simple closed-economy rational expectations model. Output, CPI inflation and the nominal interest rate are given by an Euler equation, Phillips curve and empirical monetary policy rule in the following sequence.[8]

$$\hat{Y}_t^* = \frac{1}{1+\vartheta^*}\mathbf{E}_t\hat{Y}_{t+1}^* + \frac{\vartheta^*}{1+\vartheta^*}\hat{Y}_{t-1}^* - \frac{1}{\sigma_C^*}\frac{(1-\vartheta^*)}{(1+\vartheta^*)}\left(\hat{R}_t^* - \mathbf{E}_t\hat{\pi}_{t+1}^{CPI*}\right) + \varepsilon_t^{Y*} \quad (25)$$

$$\hat{\pi}_t^{CPI*} = \frac{\iota^*}{1+\beta\iota^*}\hat{\pi}_{t-1}^{CPI*} + \frac{\beta}{1+\beta\iota^*}\mathbf{E}_t\hat{\pi}_{t+1}^{CPI*} + \frac{(1-\beta\theta^*)(1-\theta^*)}{\theta^*(1+\beta\iota^*)}\left(\hat{Y}_t^* + \sigma_C^*\frac{\hat{Y}_t^* - \vartheta\hat{Y}_{t-1}^*}{1-\vartheta^*}\right) + \varepsilon_t^{CPI*} \quad (26)$$

$$\hat{R}_t^* = \rho_{MON}^*\,\hat{R}_{t-1}^* + (1-\rho_{MON}^*)\left(\phi_\pi^*\hat{\pi}_t^{CPI*} + \phi_y^*\hat{Y}_t^*\right) + \phi_{\Delta y}^*\left(\hat{Y}_t^* - \hat{Y}_{t-1}^*\right) + \eta_t^{MON*} \quad (27)$$

σ_C^* and ϑ^* are the foreign utility curvature and external habit coefficients while θ^* and ι^* are the Calvo parameter and indexation in price-setting respectively. Monetary policy is conducted in a way similar to that of the SOE. ε^{Y*} and ε^{CPI*} are foreign AR(1) output and CPI disturbances while η^{MON*} is an innovation to monetary policy.

3 The Composition of the Real Exchange Rate

The model-implied CPI-based real exchange rate is now written as the sum of its constituent relative prices.[9] The first ingredient we define is rer^T, the international relative price of tradables, that includes the nominal exchange rate. The second component, rer^M denotes the influence of the relative price of imports in terms of the domestic tradable good, *i.e.* the terms of trade, weighted by the share of tradables in total absorption as well as the share of imports in the tradable aggregate. Finally, rer^{NT} is the internal relative price of the non-tradable good in terms of the home-produced tradable good, weighted by the share of non-tradables in aggregate absorption.

$$\widehat{REx}_t^{CPI} = \underbrace{\left(\widehat{NEx}_t + \hat{P}_t^{CPI*} - \hat{P}_{Ht}^T\right)}_{rer_t^T} \underbrace{- (1-\xi_{NT})\,\xi_M\left(\hat{P}_{Mt}^T - \hat{P}_{Ht}^T\right)}_{rer_t^M} \underbrace{-\xi_{NT}\left(\hat{P}_t^{NT} - \hat{P}_{Ht}^T\right)}_{rer_t^{NT}} \quad (28)$$

[8] We abstract from investment and fiscal policy in the foreign economy. In the foreign utility function, we assume a unitary Frisch elasticity of the labor supply while the production function is linear in hours. Justiniano and Preston (2006, 2010) use a similar New Keynesian model to model the US, and unlike in our case, they estimate the Frisch elasticity while also using wage rigidities and data. Alternatively, the foreign economy can be modelled as a vector autoregression as in Adolfson *et al.* (2007).

[9] This can easily be done by using the definition of the SOE aggregate price levels given in Equation 1 and Equation 2 in the primitive definition of the CPI-based real exchange rate, $\widehat{REx}_t^{CPI} = \widehat{NEx}_t + \hat{P}_t^{CPI*} - \hat{P}_t^{CPI}$.

Importantly, since exports of the SOE only account for a negligible share of the Foreign economy, the export price has only an indirect effect on the real exchange rate through the export demand function given in Equation 11. Note that the above equation can also be written in terms of the inverse of the mark-up of the price-setting importer, *i.e.* the law of one price gap $\widehat{NEx} + \hat{P}^{CPI*} - \hat{P}^{T}_{M}$, if one subtracts and adds the import price to rer^{T}.[10]

The above decomposition clarifies that a fall in the price of the home-produced tradable affects the real exchange rate through all three relative prices, the first leading to a real depreciation and the latter two triggering an appreciation. In the aggregate, the direction of the real exchange rate response depends on which relative price effect dominates. However, the impact of a fall in the relative price of non-tradables, originating from a fall in the absolute price of non-tradables, is *ceteris paribus* a real depreciation. Even though a rise in the relative price of non-tradables appreciates the currency in real terms, the mechanism is dissimilar to that used in the Balassa-Samuelson framework due to Balassa (1964) and Samuelson (1964). In a nutshell, the Balassa-Samuelson thesis focuses on a productivity increase in the tradable sector that leads to a decrease in prices and a concurrent rise in labor demand and the real wage. Since labor is perfectly mobile across the two sectors, costs and prices increase in the non-tradable sector, so that the *relative* price of non-tradables increases, leading to an overall appreciation of the real exchange rate. However, while the original analyses were set in a static frictionless environment, our model hinges on a CES hierarchy of prices and quantities exhibiting differing and, as we shall see in Section 4, sometimes extreme degrees of inertia. For example, prices in the non-tradable sector may even fall in response to a tradable sector-specific technology shock, in our set-up as the nominal marginal cost that is common to both sectors experiences a decline, generating a real depreciation of the currency.

[10] This alternative decomposition of the real exchange rate is given as

$$\widehat{REx}_t^{CPI} = \left(\widehat{NEx}_t + \hat{P}_t^{CPI*} - \hat{P}^T_{Mt}\right) + \left[1 - \left(1 - \xi_{NT}\right)\xi_M\right]\left(\hat{P}^T_{Mt} - \hat{P}^T_{Ht}\right) - \xi_{NT}\left(\hat{P}_t^{NT} - \hat{P}^T_{Ht}\right)$$

4 Estimation

4.1 Data

The Canada-US case provides the ideal environment to take our SOE model to the data. Canada is a small and very open economy that conducts most of its international trade transactions with only one partner, the United States. Over the period 2003-2008, the US accounted for nearly 80 percent of Canada's exports and about 67 percent of its imports (Statistics Canada 2009). Naturally, and importantly for the purpose of this paper, the IMF's trade-weighted nominal effective exchange rate for the Canadian dollar is almost identical to the Canada-US exchange rate (see Figure 1).

We follow Dotsey and Duarte (2008) and Cristadaro *et al.* (2008) in mapping the production of domestic tradables in the theoretical model to goods and that of non-tradables to services. Accordingly, we use the goods and services components of the CPI to measure the price variables for the tradable and non-tradable sectors respectively. The influence of the deviations from the law of one price is captured through the use of the bilateral export and import price series between Canada and the US. In short, for Canada, we use real consumption, real investment, nominal wage inflation, CPI Goods inflation, CPI Services inflation and the nominal interest rate. For the US, we use real GDP, CPI inflation and the nominal interest rate. Bilateral series include export price inflation, import price inflation and the nominal Canada-US exchange rate. The data spans 1986 Q.I - 2009 Q.II. The series for interest rates, price inflations and wage inflation are demeaned. All other series enter the estimation in demeaned first-differences of their natural logarithms. These twelve time series are used to identify the twelve structural innovations in the theoretical model - η^{TI}, η^{INV}, η^{MON}, η^{T}, η^{NT}, η^{WM}, η_M^{PM}, η_H^{*PM}, η^{Y*}, η^{CPI*}, η^{MON*} and η^{UIP}. Table 1 relates the model analog to the observed data series we employ and also provides the unconditional moments of the data. Other particulars are detailed in the Appendix.

4.2 Methodology

We follow the Bayesian estimation methodology of Smets and Wouters (2007) and we refer the reader to the original paper for a detailed description. In a nutshell, the Bayesian paradigm facilitates the combination of prior knowledge about structural parameters with information in the data as embodied by the likelihood function. The blend of the prior and the likelihood function yields the posterior distribution for the structural parameters which is then used for inference. The appendix provides technical details on the estimation methodology.

4.3 Priors

An overview of our priors is presented in Table 2. The prior distributions given to the estimated structural parameters are quite diffuse and comparable to those used in other studies. The parameters that are not estimated are given dogmatic priors at calibrated values. The great ratios for investment and consumption are fixed, using the sample averages, at 0.176 and 0.577. Of direct consequence to the composition of the real exchange rate in Equation 28, are the values we assign to two parameters governing the absorption of non-tradables and imports. The share of non-tradables in aggregate absorption ξ_{NT} is fixed at 0.68, the sample mean of the share of services in aggregate GDP. We obtain the share of imports in total absorption from Dib (2003) who uses a value of 0.28, the mean import-to-GDP ratio during the period 1981–2002. Using these two ratios, the steady-state share of imports in the tradable aggregate ξ_M is computed as 0.875. All other calibrated values are standard. These priors remain unaltered through all our estimations.

4.4 Results from Baseline Specification

4.4.1 Posterior Distribution

The medians and standard deviations of the posterior distributions are also reported in Table 2. The sector-specific technology shock processes exhibit low autocorrelation about 0.3, possibly due to the fact that we do not use sector-specific output in our estimation. Almost all the Phillips curves require Calvo parameter values in the neighbourhood of 0.90 to fit the persistent inflation series. The only exception is the import price inflation series, the Phillips curve of which requires a lower Calvo parameter of 0.30. However, the corresponding cost-push shock is more persistent than shocks to other Phillips curves with an AR(1) coefficient of 0.97. In contrast, for all other inflation series, the shock AR(1) coefficients are quite low at slightly below 0.60 as in the case of wages and around the 0.30 mark for the remaining cases. Similarly, while the consumption habit coefficient is very high at about 0.93, the autocorrelation of the time impatience shock is quite low at about 0.30. The estimate of the elasticity of substitution between non-tradable and tradable goods, at about 1.14, is higher than those found for the US by Rabanal and Tuesta (2007) and Cristadoro *et al.* (2008). The former find an extremely low value of 0.13 while the latter find higher values ranging between 0.50 and 0.80. The trade elasticity is about 1.5 which is higher than the value of 0.80 obtained by Dib (2003) and lower than the mean of 1.80 obtained by Justiniano and Preston (2006) in similar exercises using Canadian data. We comment on the sizes of selected shock innovations in the following sub-sections. Other parameters are in the ballpark of those estimated for the US and the Euro-Area by Smets and Wouters (2003, 2007).

4.4.2 The Dynamics of the Real Exchange Rate

In Figure 2, we present the responses of the three components of the real exchange rate, the impacts of (a) the international relative price of tradables (b) the relative price of imports in terms of home-produced tradables and (c) the internal relative price of non-tradables in terms of home-produced tradables, to various structural shocks. To prevent confusion, note that our definition of the influences from the relative prices, which are exhibited in Figure 2, subsumes both the weights and the signs so that the sum of the responses of the three components add up to the aggregate real exchange rate response. In Figure 3, we also present the dynamics trigered by the main shocks for a different decomposition of the real exchange rate defined in Footnote 10, viewed in terms of the law of one price gap. In our discussion, shocks are classified, admittedly imperfectly, into 'direct' shocks to the relative prices in Equation 28, shocks to the real marginal cost, shocks to monetary policy and domestic demand and external shocks (of US origin).

Direct Shocks to the Relative Prices: The deviation from uncovered interest parity appears as a wedge between the Canadian and the US nominal interest rates, raising the former while lowering the latter. Since this shock acts a risk-premium for Canadian borrowers, the currency depreciates very strongly in nominal terms. Imports become more expensive for the SOE, but due to nominal stickiness, the rise in import prices is less than one-to-one to the movement in the nominal exchange rate. The terms of trade deteriorates and has an appreciation effect on the real exchange rate. The rise in import prices raises CPI and since nominal marginal costs rise, it increases the price of domestic tradables and non-tradables. However, the movement in the relative price of non-tradables is a gentle fall, causing a mild though significant depreciation effect. In the aggregate, the real exchange rate deteriorates and mimics the behavior of the international relative price of tradables, with the nominal exchange rate playing the pivotal role.

On the other hand, the immediate impact of the tradable sector-specific technological disturbance is a fall in the price of tradable goods and a slow rise in aggregate quantities. This negative effect leads to a fall in aggregate CPI, decreasing the nominal costs of the non-tradable sector inducing a mild fall in prices in that sector. Hence, the relative price of non-tradables strongly increases and has an appreciation effect on the real exchange rate. Simultaneously the relative price of imports in terms of the domestic tradable also increases reinforcing the appeciation effect. However, the international relative price of tradables rises strongly. This positive movement negates the negative influences of the two other relative prices and overall, the movement is statistically insignificant.

A technology shock in the non-tradable sector induces a fall in prices which reflects in a fall in CPI in the aggregate. This fall in aggregate CPI is stronger than in the case of the tradable sector technology shock, as non-tradables are the dominant component of the SOE GDP. The fall in nominal costs also leads to a mild decrease in the price of tradable goods, but in the net, the relative price of non-tradables in terms of tradables decreases and exerts a depreciation effect on the real exchange rate. The effect of this shock is statistically insignificant on the other relative prices. Overall, the real exchange rate follows the dynamic path of the (depreciation effect from the) relative price of non-tradables and moves in almost in the same quantum at most horizons.

The size of the innovation of the import price innovation is quite high at almost 4.5 percent, reflecting the high volatility of the data series. The shock generates a strong rise in import prices and hence acts as an exogenous deviaton from the law of one price (See also Figure 3 for the persistent fall in the law of one price gap). The subsequent sharp push to CPI generates a slow and persistent rise in prices of non-tradables, tradables and exports, through the nominal cost channel. Observe that the quantitative impact on the relative price of imports is stronger than that of the response of the relative price of non-tradables to the non-tradable sector-specific shock. The response of the international relative price of tradables is insignificant while the relative price of non-tradables falls gently. The appreciation effect from the relative price of imports swamps the much weaker depreciation effect from the relative price of non-tradables and the currency strongly appreciates and replicates the effect emanating from the relative price of imports.

In contrast, despite the high magnitude of the export price innovation, at about 2.5 percent, the exchange rate response is mild as the shock only has an indirect impact through the foreign export demand function. The rise in prices lowers foreign demand for the SOE exports. The SOE experiences a fall in consumption, investment and production and the lack of demand causes prices in both the tradable and non-tradable sectors to fall. The relative price of non-tradables however rises gently. The monetary authority lowers the interest rate to counter the fall in economic activity and the currency experiences a nominal depreciation, though the movement is statistically significant only for a couple of quarters. Import prices rise modestly but the response becomes insignificant quite quickly and the terms of trade worsens more due to the fall in the price of domestic tradables. The overwhelming influence on the exchange rate is from the international relative price of tradables which rises. The currency depreciation is statistically insignificant after about 4 quarters.

Shocks to the Real Marginal Cost: The cost-push shock to the real wage raises the prices of non-tradables and tradables slowly while the relative price of non-tradables falls. The impact on import prices is insignificant, but the rise in the prices of home tradables ensures that the terms of trade improves. The international relative price of tradables falls slowly due to the nominal appreciation triggered by the rise in the interest rate in reaction to the price hike. Cumulatively, the response of the real exchange rate is insignificant.

The investment-specific technology shock increases the conversion of the final good into the capital stock and the slow fall in marginal costs reflects in the decrease in prices in both sectors. Since prices in the non-tradable sector are slightly stickier than in the tradables sector, the latter falls more causing a rise in the relative price of non-tradables and generates a very mild appreciation effect on the currency. The monetary authority reacts to the rise in output and raises the nominal interest rate, immediately appreciating the currency in nominal terms, decreasing the international relative price of tradables. The appreciated currency leads to a decline in import prices and improves the SOE terms of trade. In the aggregate, the very mild appreciation effect emanating from the relative price of non-tradables and the much stronger appreciation effect from the international relative price of tradables goods dominates the (initially) positive terms of trade effect causing a real appreciation of the currency on impact. The real exchange rate follows the international relative price of tradables closely as the sign of the response reverses after about three years.

Domestic Monetary Policy and Demand Shocks: The rise in the SOE nominal interest rate induces a fall in domestic demand, decreases prices in the tradable and non-tradable sectors and appreciates the currency in nominal terms. The appreciated currency leads to a fall in the price of imports and in combination with the (stronger) fall in the price of the home-produced tradable good, significantly improves the terms of trade. The dominant effect is exerted by the international relative price of tradables and the currency strongly appreciates in real terms, almost on a one-to-one basis.

The consumption shock is modelled as an exogenous increase in the economy's time impatience to consume, raising prices in both intermediate sectors slowly. The predominant influence in this case is from the international relative price of tradables that appreciates very strongly due to the currency's nominal appreciation that follows the hike in the interest rate and the aggregate real exchange rate responds almost identically in both direction and quantum.

Foreign Economy Shocks: The foreign demand shock affects the foreign Euler equation and raises aggregate demand, and importantly for the SOE, the demand for exports rises which stimulates production in the SOE. Nominal interest rates rise in both economies, in the SOE in a lesser quantum than in the bigger economy and the SOE currency depreciates in nominal terms. Foreign CPI also rises due to the demand shock and adds to the cost of procurement of the foreign good for the SOE importer. This raises import prices and deteriorates the SOE terms of trade. Prices fall persistently in both intermediate sectors as domestic resources are spent to feed the foreign output boom. The relative price of non-tradables falls gently but significantly for about four years, depreciating the currency. This is complemented by the much stronger dynamics of the international relative price of tradables, as the currency experiences a strong real depreciation.

On the other hand, the shock to the foreign Phillips curve raises the procurement price of foreign tradables, deteriorating the SOE terms of trade. The impact on the relative price of non-tradables is insignificant. The real exchange rate inherits the dynamic behavior of the international relative price of tradables over the forecast horizon. The foreign interest rate shock evokes responses that are qualitatively symmetric to those generated by the SOE interest shock and the SOE currency depreciates. The bottomline is that in response to all the US shocks, the real exchange rate follows the time path of the international relative price of tradables.

4.4.3 Variance Decomposition

We now dissect the variance of the forecast errors of the real exchange rate and its component prices to evaluate the relative contributions of the twelve shocks embedded in the model, in the first four columns of Table 3. Additionally, in the last column, we also report the decomposition for the deviation from the law of one price which is simply the difference between the international relative price of tradables and the relative price of imports in terms of the home-produced tradable.

The random deviation from interest parity is the main driver of the Canada-US real exchange rate, accounting for above 60 percent on impact, declining to about 40 percent over the horizon of 10 years. Justiniano and Preston (2006) obtain comparable results for Canada while Cristadoro *et al.* (2008) and Rabanal and Tuesta (2009) report the dominance of this shock in the decomposition of the Euro-Dollar exchange rate. The combined influence of sector-specific technology shocks pales in comparison to that of the UIP shock, at less than 5 percent at any horizon. Between the two technology shocks, the non-tradable sector disturbance, through its strong depreciation effect on the currency, is relatively more potent. As we noted in the impulse response analysis, the tradable sector shock generates opposing effects from the constituent relative prices and the overall movement observed in the real exchange rate is statistically insignificant. The cost-push shock to import prices is much more important than the internal sector-specific shocks, with its influence increasing over the horizon from about 7 percent on impact to about 18 percent at a 10 year horizon. In contrast, the export price shock despite being of high volatility, is less important contributing less than 5 per cent at any horizon. This result is an artifact of our SOE assumption that allows for only an indirect impact of export prices on the exchange rate through the export demand function and the relevant dynamics in foreign absorption.[11]

The Canadian nominal interest rate innovation is important, contributing about 15 percent on impact, with its influence mildly decreasing over time. Shocks to the real wage as well as the components of aggregate demand - investment and consumption - have very little influence, together accounting for less than 10 percent at all forecast-horizons. Similar to Justiniano and Preston (2006, 2010), we also find that shocks of US origin

[11] It may be a reasonable conjecture that the export price shock would matter more in a two-country set-up when the export price and corresponding data series enter the definition of the real exchange rate directly.

contribute negligibly to the forecast volatility.

What shocks drive the component relative prices? Not surprisingly, the variance decomposition of the international relative price of tradables, the predominant player in the impulse responses, is very similar to that of the real exchange rate, except for the milder impact of the import price mark-up shock. The UIP shock exerts a very potent influence on the international relative price of tradables, almost replicating the pattern observed for the real exchange rate over time. The UIP shock is less important for the relative price of imports, accounting for below 40 percent on impact and 20 percent in the long run, due to the strong influence of the import price mark-up shock whose influence increases over time from under 40 percent to about 55 percent at the 10 year mark. Interestingly, the relative price of non-tradables, is dominated by tradable sector technology shocks rather than those in the non-tradable sector. While nominal stickiness, shock size and persistence are only slightly different between the two sectors, since tradables constitute a smaller proportion of GDP, the tradable sector shock has a milder negative effect on the the aggregate price level and hence the nominal marginal costs common to both sectors, thereby generating only a slight decline in the absolute price of non-tradables. Consequently, the *relative* price moves strongly. On the other hand, the non-tradable sector shock induces a persistent decline in nominal marginal costs and hence also in the price of tradables. Thus the variability generated in the relative price of non-tradables is more gentle than in the former case. Finally, the law of one price gap (not explicitly defined in the disaggregation given in Equation 28), which is essentially the difference between the first two relative prices that we examined, is almost exclusively driven by two shocks: the import price mark-up shock and the UIP shock. However, the impact of the UIP shock is short-lived and in the long run, the import mark-up shock drives the deviation from the law of one price.

A highlight of the variance decomposition is the modest influence of tradable or non-tradable sector-specific disturbances in determining real exchange rate dynamics. Dotsey and Duarte (2008) and Corsetti, Dedola and Leduc (2008) have demonstrated that theoretical DSGE models using non-tradables in combination with other frictions such as nominal stickiness can replicate the real exchange rate persistence and volatility observed in the data, conditional on specific structural shocks and parametric configurations. While our methodology relies considerably on the exogenous shocks to match the data, the impulse responses presented in Subsection 4.4.2 indicate that an impetus from a disturbance specific to the non-tradable sector can indeed help the relative price of non-tradables guide the behavior of the exchange rate, quite in the spirit of Dotsey and Duarte (2008). However, in a broader context, when we allow the exchange rate to be driven by a wider array of stochastic disturbances, the tradable component, *i.e.* the international relative price of tradables and the relative price of imports and associated shocks generate even stronger real exchange rate dynamics. Naturally, the influence of the non-tradable sector shock diminishes to negligible proportions in the variance decomposition. In fact, import price shocks appear to be more potent in driving the exchange rate, even though the relative price of imports is assigned a much lower weight in the composition of the real exchange rate.[12]

5 Alternative Specifications

We now assess how the contributions of the relative prices and associated disturbances change when we subject the baseline model to perturbations, adding or removing elements one at a time. The estimation results are reported in Table 3 together with those obtained in the baseline case. The impulse response functions of the relative prices of non-tradables and imports and the real exchange rate and the variance decompositions of the real exchange rate at a 1 year horizon are presented in Table 4 and Table 5 respectively. In each estimation, we maintain equality between the number of shocks and observables that we use.

The Real Exchange Rate as Observable Instead of using nominal exchange rate depreciation as the observable series in the estimation, we use the demeaned level of the CPI-based real exchange rate computed from the data, as in Rabanal and Tuesta (2007) and Cristadoro *et al.* (2008). Most parameter estimates barely differ. However, the size of the import price innovation decreases considerably from 4.34 in the baseline case to about 3.50 while the UIP innovation increases from 0.28 to 0.40.[13] The new parameter estimates hardly matter for the qualitative contributions of the relative prices in the aggregate

[12] Given our calibration, the weights assigned to the relative prices of imports and non-tradables in the composition of the exchange rate are $(1-\xi_{NT})\,\xi_M = 0.28$ and $\xi_{NT} = 0.68$ respectively.

[13] Demeaning a depreciation rate, *i.e.* a growth rate, is equivalent to assuming a linear trend in the level of the nominal exchange rate. The detrended exchange rate is less volatile than the demeaned level of the real exchange rate, explaining the rise in the innovation size.

real exchange response. As can be seen in Table 4, the direction of the real exchange rate response is predominantly determined by the relative price of non-tradables only in the case of the non-tradable sector technology shock. But due to the increased size of the UIP innovation, it makes a higher contribution of about 65 percent in the variance decomposition.

Fixing Nominal Stickiness Since our estimates of price and wage stickiness are at the higher end of the range reported in the literature, we check if fixing these parameters at more reasonable values will impact our main results. Somewhat arbitrarily, we set all Calvo parameters for the price and wage Phillips curves at 0.75 implying a price change every 4 quarters while fixing all indexation parameters at 0.25. Notably, the persistence coefficients of all shocks affecting the Phillips curves are now higher than in the baseline case. However, the flavor of the main results does not change as the international relative price of tradables dominates the dynamics of the exchange rate in most impulse responses. The UIP shock still contributes about 45 percent of the forecast variance.

PPI We now experiment with an alternative measure of home-produced tradable good prices. Instead of using CPI Goods as in Cristadoro *et al.* (2008), we follow Rabanal and Tuesta (2007) in employing the producer price index, as it may be relatively less contaminated by non-tradable elements as the prices of distribution services. The persistence parameter of the tradable sector technology shock increases noticeably from 0.21 in the baseline case to 0.35, while other parameter values remain similar. This however has little impact on the variance decomposition as the UIP shock continues to dominate.

Producer Currency Pricing The procurement cost of the tradable good from the foreign or home producer is transmitted immediately to import and export prices facing the aggregation sector. In other words, the law of one price gap induced by the price-setting importer in the baseline model disappears. Consequently, we remove the import and export price series and the corresponding cost-push shocks from the estimation. As in previous specifications, the relative price of non-tradables matters for the aggregate movement in the real exchange rate only in the case of the non-tradable sector-specific shock. The variance decomposition is still favor of the UIP shock.

No UIP Shock and Nominal Exchange Rate Data As an extreme experiment, we now impose pure uncovered interest parity and simultaneously remove the nominal exchange rate series from the estimation.[14] The most noticeable change is in the estimate of the Calvo parameter in the import Phillips curve which increases dramatically from the 0.30 to about 0.80. At the same time, the persistence of the corresponding shock decreases from 0.97 to about 0.30. The innovation of the import price shock also shows a substantive decline in size from about 4.30 percent in the baseline case to about 1.80 percent, indicating that the presence of the volatile nominal exchange rate series in the marginal costs of the importing firm, adds considerably to the innovation size. Qualitatively, the real exchange rate follows the relative price of non-tradables in response to both sector-specific shocks, although the dynamic induced by the tradable sector shock is quantitatively much weaker. Note however, that domestic sector-specific disturbances still exert a negligible influence, in unison accounting for less than 5 percent. Despite the lower estimated volatility of the import price shock, it contributes about 14 percent of the variance and the export price shock's contribution rises to 13 percent. Importantly, quite distinct to the baseline case, the US demand shocks via SOE export sales exert a considerable influence on the exchange rate. It contributes about 23 percent as does the Canadian monetary policy innovation.

Other Checks[15] The main results favoring the importance of the purely tradable component of the real exchange rate hold when (a) we remove the sector-specific technology shocks and instead use price-mark up shocks in each intermediate sector (b) μ_{NT} the elasticity of substitution between non-tradables and tradables is set to 0.001 implying near Leontief complementarity between the two and (c) physical capital accumulation is removed from the model.

[14] This experiment is necessary because the extremely potent influence of the UIP shock may mask the importance of other shocks in the model. Observe that a variance decomposition is a 'relative' exercise. Even if a shock generates a strong impulse response, its contribution to aggregate volatility will be dominated by other shocks that generate even stronger impulses. Since the nominal exchange rate is now withdrawn from the empirical exercise, our focus is on the relative price of imports and the relative price of non-tradables. The percentage contributions of shocks have to be interpreted in a model-specific context.

[15] These results are not exhibited and are available on request.

6 Conclusion

This paper assessed the dynamic interaction between the real exchange rate and its component relative prices in a small open economy DSGE model estimated on Canada-US macroeconomic time series over 1986-2009. Consistent with the theoretical literature, *e.g.* Dotsey and Duarte (2008), the results indicate that a strong impetus from a disturbance specific to the non-tradable sector can indeed help the relative price of non-tradables in terms of home-produced tradables guide the behavior of the exchange rate. However, our subsequent findings somewhat challenge the importance of the relative price of non-tradables in a broader context: the purely tradable component, *i.e.* the international relative price of tradables as well as the relative price of imports, clearly generates even stronger aggregate real exchange rate dynamics for all other shocks *irrespective* of the structural origin of the disturbance. The two prime players in the forecast variance decomposition of the real exchange rate are the UIP shock and the import price mark-up shock, both of which generate deviations from the law of one price. The former exerts its influence mostly via the international relative price of tradables while the latter generates changes predominantly in the relative price of imports. The influence of internal sector-specific disturbances on real exchange rate variability pales in comparison. Our findings complement the statistical results favoring the importance of its purely tradable component for the real exchange rate reported by Engel (1999), Chari, Kehoe and McGrattan (2002) and Wolden Bache *et al.* (2009).

We must however emphasize an important caveat. As mentioned earlier in the text, there is no unique way of positioning non-tradables in a DSGE model and results may be sensitive to the set-up. Bems (2008) documents that investment also has a substantial non-traded component, a feature we cannot control for given our simple aggregation choice. Differentiating between consumption and investment deflator-based real exchange rates may be a useful avenue to explore in future research.

A Appendix

A.1 Data series

For Canada, we use the Statistics Canada database for GDP at market prices, personal consumption expenditures, business gross fixed capital formation, overnight call money financing rate, CPI, CPI Goods, CPI Services and the bilateral export and import prices as well as the nominal exchange rate with the US. The Canada-US import-export prices are Paasche current-weighted indices broadly based on prices of commodities that include agricultural products and livestock, crude materials as oil along with finished products as machinery and automobiles. The import-export prices reported in CanSim Tables 228.0020 (1986Q1-1997Q4 Discontinued), 228.0039 (1997Q1-2007Q4 Discontinued) and 228.0051 (2002Q1-till date) are concatenated using the conversion factors for dates that overlap between these series. This limits our sample period to 1986Q1-2009Q2. The series on the producer price index and nominal wages are gleaned from the International Financial Statistics database of the International Monetary Fund. We obtain nominal GDP, CPI and the federal funds rate for the US from the FRED II database. All raw series, except the interest rates, are seasonally adjusted by the Census X12 method. The demeaned nominal interest rates are divided by 4 to translate them into quarterly terms. We express all other series as indices based on 2002Q2 and then multiply their natural logarithms by 100. These series are fed into the model in demeaned first differences while the nominal interest rates enter the estimation in levels. For the first variant of the model, the real exchange rate is computed from the nominal exchange rate and the aggregate CPIs from the two countries and then logged and demeaned. This variable enters the estimation in levels.

A.2 Estimation

We use 525000 iterations of the Random Walk Metropolis Hastings algorithm to simulate the posterior distributions and achieve acceptance rates of about 40 percent in all our specifications. We monitor the convergence of the marginal posterior distributions using CUMSUM statistics as defined by Bauwens *et al.* (1999). We discard the initial 25000 draws to compute the posterior moments in each case. The distributions of impulse response functions and variance decompositions that we present are computed from 150 random draws from the posterior. This strategy ensures that our results are not contingent on a particular vector of parameter values such as the posterior median or the mode.

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FIGURES

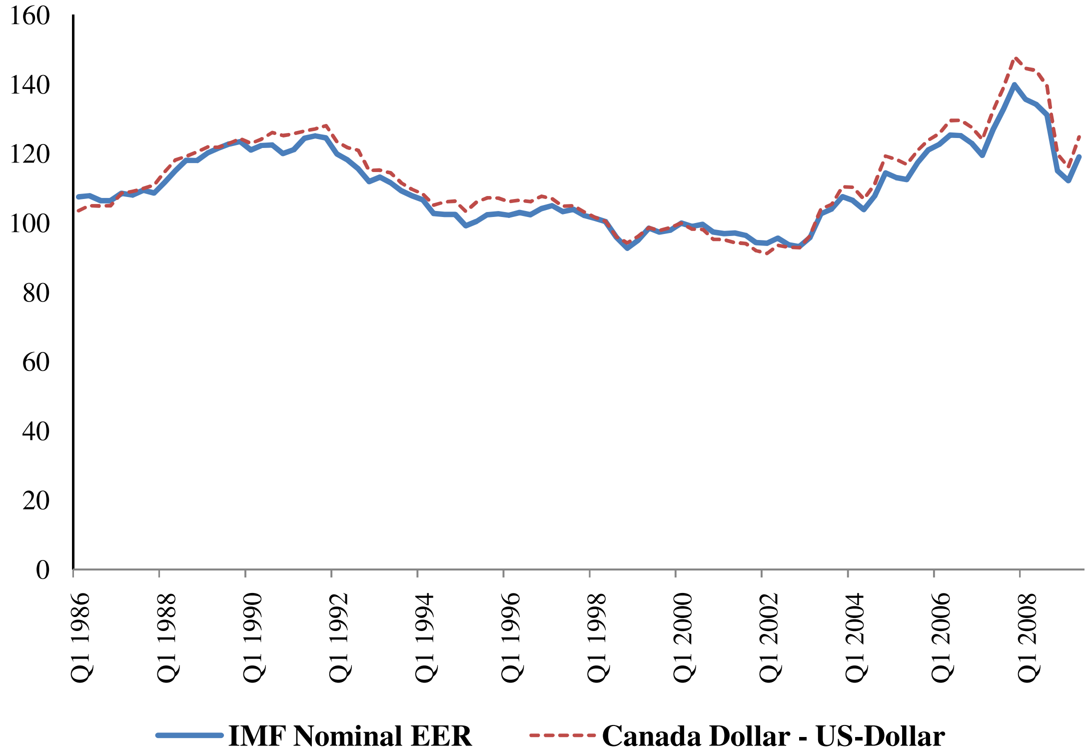

Figure 1: The Canada-US Nominal Exchange Rate (1986-2009)

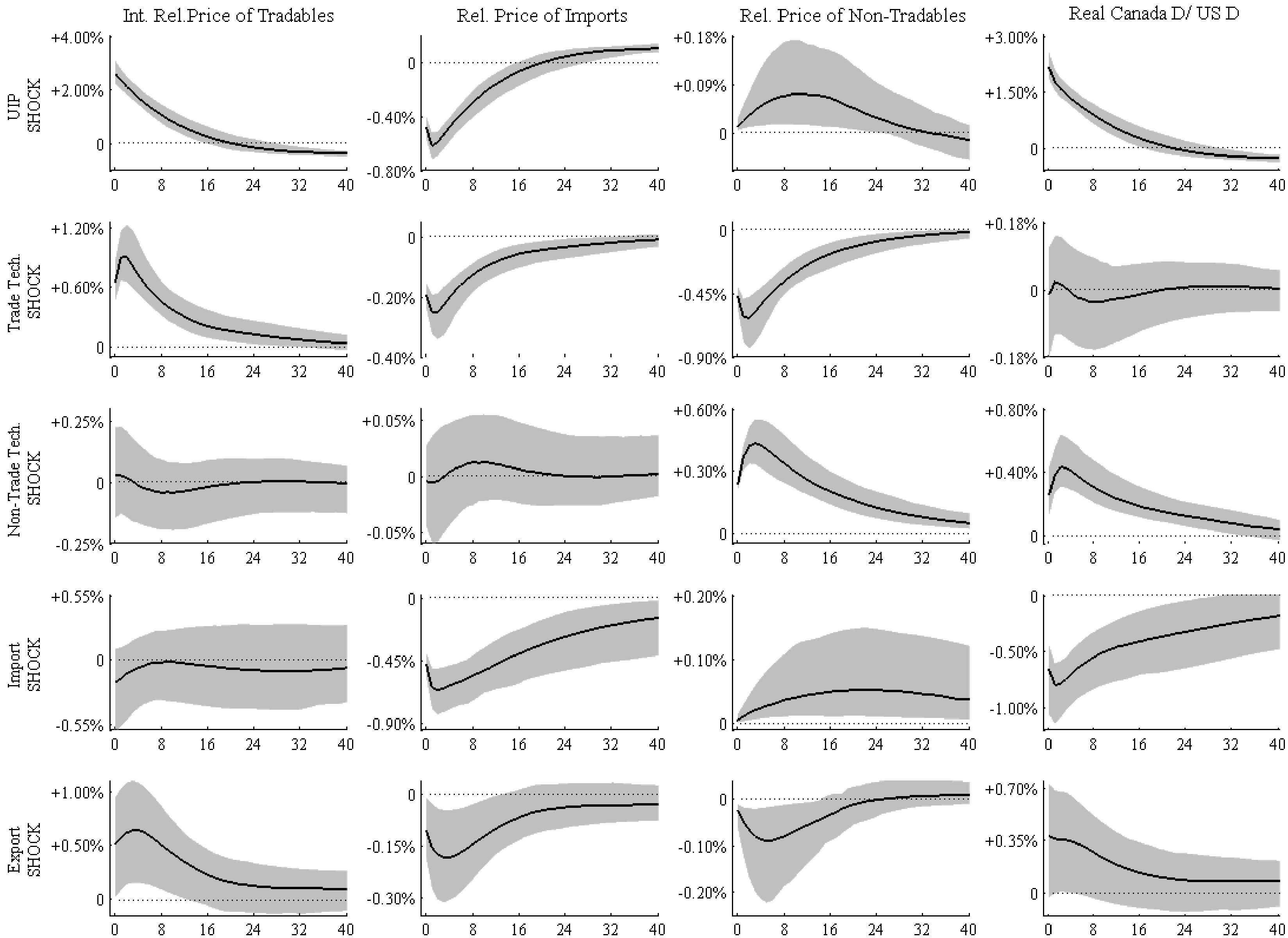

Figure 2: The Dynamic Responses of the Components of the Canada-US CPI-based Real Exchange Rate to a one SD Shock

Note: The median IRF (thick black line) and the 5th and 95th percentiles (shaded area) are based on 150 random draws from the posterior distribution. The components of the real exchange rate are multiplied by the sign and the weights in the definition given in the main text, so that the IRFs of the three components sum up to the total response presented in the last column.

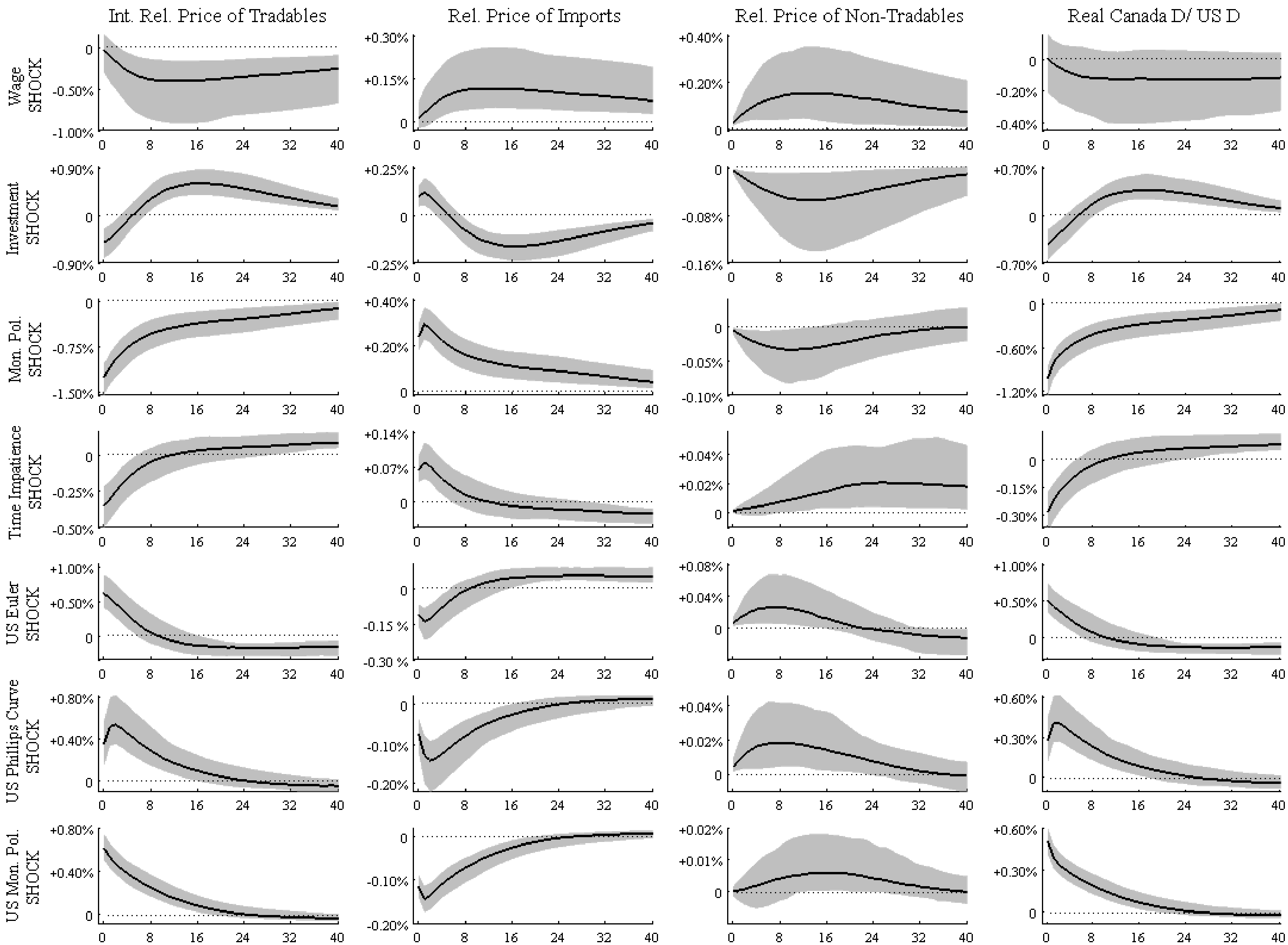

Figure 2 (Contd)

Note: The median IRF (thick black line) and the 5th and 95th percentiles (shaded area) are based on 150 random draws from the posterior distribution. The components of the real exchange rate are multiplied by the sign and the weights in the definition given in the main text, so that the IRFs of the three components sum up to the total response presented in the last column.

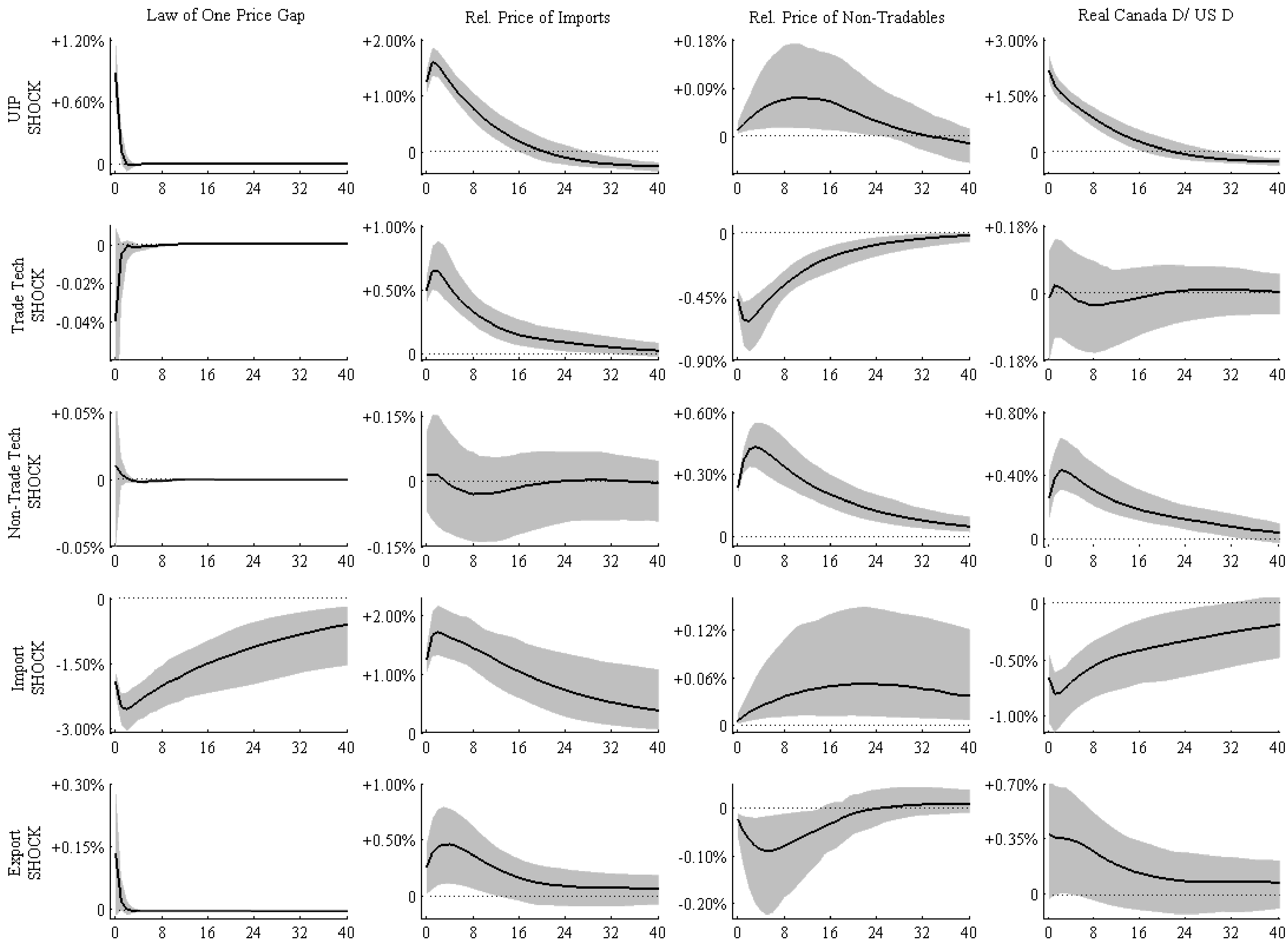

Figure 3: The Dynamic Responses of the Law of One Price Gap and other components of the Real Exchange Rate to a one SD Shock

Note: The relative price of imports is weighted differently in this decomposition of the exchange rate (See Footnote 10 in the main text) and hence the direction of its response is opposite to those exhibited in Figure 2. The median IRF (thick black line) and the 5th and 95th percentiles (shaded area) are based on 150 random draws from the posterior distribution. The components of the real exchange rate are multiplied by the sign and the weights in the definition given in the main text, so that the IRFs of the three components sum up to the total response presented in the last column.

TABLES

Table 1: Unconditional Moments of the Data

Series	Canada Mean	Canada SD	US Mean	US SD	Model Canada Variable (Filtered Data)
Real Consumption Growth	0.36	0.73	-	-	$\Delta\hat{C}_t$
Real Investment Growth	0.32	2.55	-	-	$\Delta\hat{I}_t$
Nominal Interest Rate	1.40	0.77	1.17	0.56	$\hat{R}_t$
CPI Inflation	-	-	0.72	0.51	$\hat{\pi}_t^{CPI}$
CPI Goods Inflation (T)	0.47	0.79	-	-	$\hat{\pi}_{Ht}^{T}$
CPI Services Inflation (NT)	0.75	0.43	-	-	$\hat{\pi}_t^{NT}$
Import Price Inflation	-0.42	2.57	-	-	$\hat{\pi}_{Mt}^{T}$
Export Price Inflation	0.12	3.21	-	-	$\hat{\pi}_{Ht}^{*T}$
Nominal Wage Inflation	0.61	0.97	-	-	$\Delta\hat{w}_t + \hat{\pi}_t^{CPI}$
Depreciation of Can Dol/USD.	-0.20	2.97	-	-	$\Delta\widehat{Nex}_t$
Demeaned Real Can Dol/USD	-	12.47	-	-	$\Delta\widehat{Rex}_t^{CPI}$

Note: The natural logarithms of all time series except the nominal interest rate are multiplied by 100 and hence all the numbers exhibited above can be interpreted as percentages. The T and NT in parentheses indicate 'tradables' and 'non-tradables' respectively.

Table 2: Priors and Posterior Moments of Structural Parameters in Model Variants

Symbol	Description	PRIOR (P1, P2)	POSTERIOR DISTRIBUTION (Median; SD) Baseline	RExLevel	FixCalvo	PPI	PCP	No UIP-NEx
μ_M	Trade Elasticity	G (1.00, 0.75)	1.46; 0.52	1.71; 0.67	1.10; 0.18	1.58; 0.48	0.25; 0.17	2.58; 0.44
μ_{NT}	Price Elasticity of NT	G (1.00, 0.75)	1.14; 0.51	0.87; 0.61	0.43; 0.27	1.33; 0.53	2.08; 0.60	0.48; 0.38
σ_C	Utility Curvature	G (2.00, 0.50)	2.31; 0.53	2.30; 0.52	2.18; 0.49	2.27; 0.52	2.30; 0.53	2.22; 0.52
σ_C^*	US Utility Curvature	G (2.00, 0.50)	1.59; 0.36	1.59; 0.37	1.09; 0.21	1.58; 0.37	1.57; 0.35	1.58; 0.35
ϑ	External Habit	B (0.50, 0.15)	0.93; 0.04	0.93; 0.04	0.91; 0.05	0.92; 0.06	0.93; 0.04	0.93; 0.10
ϑ^*	US External Habit	B (0.50, 0.15)	0.50; 0.09	0.49; 0.10	0.38; 0.06	0.51; 0.10	0.50; 0.09	0.44; 0.07
ψ	Investment Adj.Cost	N (4.00, 1.00)	6.10; 0.82	6.07; 0.82	5.51; 0.78	5.94; 0.83	4.84; 0.87	5.20; 0.78
θ_H^T	T Calvo	B (0.80, 0.10)	0.93; 0.02	0.93; 0.02	-	0.93; 0.02	0.92; 0.02	0.92; 0.01
ι_H^T	T Indexation	B (0.50, 0.15)	0.20; 0.08	0.20; 0.08	-	0.26; 0.10	0.20; 0.08	0.17; 0.07
θ^{NT}	NT Calvo	B (0.80, 0.10)	0.96; 0.01	0.96; 0.01	-	0.98; 0.01	0.97; 0.01	0.94; 0.01
ι^{NT}	NT Indexation	B (0.50, 0.15)	0.28; 0.13	0.29; 0.13	-	0.24; 0.12	0.23; 0.13	0.33; 0.11
θ_H^{*T}	Export Calvo	B (0.80, 0.10)	0.87; 0.03	0.85; 0.03	-	0.83; 0.04	-	0.72; 0.08
ι_H^{*T}	Export Indexation	B (0.50, 0.15)	0.22; 0.08	0.23; 0.09	-	0.22; 0.08	-	0.32; 0.12
θ_M^T	Import Calvo	B (0.80, 0.10)	0.27; 0.05	0.30; 0.05	-	0.28; 0.06	-	0.80; 0.08
ι_M^T	Import Indexation	B (0.50, 0.15)	0.27; 0.12	0.20; 0.10	-	0.26; 0.11	-	0.29; 0.10
θ_W	Wage Calvo	B (0.80, 0.10)	0.93; 0.03	0.93; 0.03	-	0.96; 0.02	0.94; 0.02	0.91; 0.03
ι_W	Wage Indexation	B (0.50, 0.15)	0.22; 0.08	0.22; 0.08	-	0.22; 0.08	0.19; 0.08	0.23; 0.08
θ^*	US Calvo	B (0.80, 0.10)	0.97; 0.01	0.97; 0.01	-	0.97; 0.01	0.97; 0.01	0.97; 0.01
ι^*	US Indexation	B (0.50, 0.15)	0.23; 0.09	0.24; 0.09	-	0.23; 0.09	0.23; 0.09	0.24; 0.10
ρ_{MON}	Interest Smoothing	B (0.50, 0.15)	0.94; 0.01	0.94; 0.01	0.94; 0.01	0.95; 0.01	0.93; 0.01	0.95; 0.01
ρ_{MON}^*	US Interest Smoothing	B (0.50, 0.15)	0.91; 0.02	0.91; 0.02	0.89; 0.02	0.91; 0.02	0.91; 0.02	0.92; 0.02
ϕ_π	Mon. Pol. Inflation	G (0.50, 0.25)	2.43; 0.52	2.34; 0.50	2.36; 0.44	2.25; 0.52	2.61; 0.54	1.47; 0.39
ϕ_π^*	US Mon. Pol. Inflation	G (0.50, 0.25)	2.13; 0.39	2.18; 0.40	2.55; 0.37	2.14; 0.39	2.04; 0.35	2.51; 0.43
ϕ_y	Mon. Pol. GDP	G (0.50, 0.25)	0.08; 0.04	0.07; 0.04	0.05; 0.03	0.11; 0.05	0.06; 0.03	0.12; 0.07
ϕ_y^*	US Mon. Pol. GDP	G (0.50, 0.25)	0.08; 0.04	0.09; 0.04	0.05; 0.03	0.09; 0.04	0.09; 0.04	0.09; 0.05
$\phi_{\Delta y}$	Mon. Pol. GDP change	G (0.50, 0.25)	0.11; 0.02	0.12; 0.02	0.11; 0.02	0.11; 0.02	0.12; 0.02	0.12; 0.02
$\phi_{\Delta y}^*$	US Mon. Pol. GDP change	G (0.50, 0.25)	0.17; 0.03	0.17; 0.03	0.20; 0.03	0.17; 0.03	0.17; 0.03	0.18; 0.03

CALIBRATED PARAMETERS

Symbol	Description	Value
β	Discount Factor	0.99
α	Share of Capital in Production	1/3
δ	Quarterly Rate of Capital Depreciation	0.025
χ_P	Sub. Elasticity of Goods Varieties	10
χ_W	Sub. Elasticity of Labor Varieties	10
σ_N	Inverse of Frisch Elasticity	2
κ	Cost of adjusting foreign assets	0.001
Ξ_I	St-state share of investment in GDP	0.1760
Ξ_C	St-state share of consumption in GDP	0.5770
ξ_{NT}	Share of NT in GDP	0.68
ξ_M	Implied Import-share in T Aggregate	0.8750
κ_N	Implied Share of NT Demand for Lab.	0.5419
κ_K	Implied Share of NT Demand for Cap.	0.8255

Note: '**Baseline**' indicates the baseline SOE model. '**RExLevel**' indicates the check in which we use the real exchange rate as observable instead of the nominal currency depreciation. '**FixCalvo**' calibrates the price and wage stickiness parameters at lower values. '**PPI**' uses the producer price index to measure tradable goods prices. '**PCP**' imposes the law of one price and does not use import-export price data and shocks. '**No UIP-NEx'** does not use nominal exchange rate data and the UIP shock. G= Gamma, B= Beta, N= Normal distributions. P1= Mean and P2= Standard Deviation. Posterior moments are computed using 500000 draws from the distribution simulated by the Random Walk Metropolis algorithm. T and NT represent the tradable and the non-tradable sectors respectively.

Table 2 (Contd): Priors and Posterior Moments of Shock Parameters in Model Variants

Symbol	Description	PRIOR (P1, P2)	POSTERIOR DISTRIBUTION (Median; SD) Baseline	REx Level	FixCalvo	PPI	PCP	No UIP-NEx
AR(1) and MA(1)								
ρ_{UIP}	UIP	B (0.50, 0.15)	0.94; 0.02	0.92; 0.02	0.94; 0.02	0.94; 0.02	0.95; 0.02	-
ρ^{Ttech}	T Sector Technology	B (0.50, 0.15)	0.21; 0.08	0.21; 0.08	0.55; 0.09	0.35; 0.10	0.19; 0.08	0.22; 0.08
ρ^{NTtech}	NT Sector Technology	B (0.50, 0.15)	0.35; 0.14	0.32; 0.14	0.80; 0.05	0.41; 0.13	0.43; 0.15	0.23; 0.10
ρ_M^{PM}	Import Price Mark-up	B (0.50, 0.15)	0.97; 0.02	0.96; 0.02	0.60; 0.07	0.96; 0.02	-	0.33; 0.13
ρ_H^{*PM}	Export Price Mark-up	B (0.50, 0.15)	0.22; 0.08	0.22; 0.08	0.43; 0.07	0.25; 0.10	-	0.36; 0.13
ρ_{WM}	Wage Cost-Push AR(1)	B (0.50, 0.15)	0.58; 0.09	0.58; 0.09	0.63; 0.08	0.57; 0.09	0.56; 0.09	0.58; 0.08
v_{WM}	Wage Cost-Push MA(1)	B (0.50, 0.15)	0.40; 0.11	0.41; 0.12	0.41; 0.12	0.40; 0.11	0.40; 0.12	0.41; 0.11
ρ_{IST}	Investment Specific Technology	B (0.50, 0.15)	0.75; 0.06	0.73; 0.07	0.73; 0.07	0.78; 0.05	0.73; 0.08	0.47; 0.12
ρ_{TI}	Consumption Time Impatience	B (0.50, 0.15)	0.28; 0.10	0.28; 0.10	0.28; 0.11	0.30; 0.12	0.29; 0.11	0.30; 0.18
ρ^{Y*}	US Demand (Output)	B (0.50, 0.15)	0.89; 0.06	0.90; 0.07	0.91; 0.03	0.88; 0.07	0.88; 0.05	0.96; 0.02
ρ^{CPI*}	US Price	B (0.50, 0.15)	0.25; 0.10	0.25; 0.10	0.79; 0.08	0.25; 0.09	0.24; 0.09	0.24; 0.10
INNOVATIONS								
$100\sigma_{UIP}$	UIP	IG (0.1, 2)	0.28; 0.06	0.40; 0.08	0.28; 0.06	0.27; 0.06	0.20; 0.05	-
$100\sigma^{Ttech}$	T Sector Technology	IG (0.1, 2)	0.38; 0.04	0.38; 0.04	0.42; 0.05	0.43; 0.05	0.39; 0.04	0.39; 0.04
$100\sigma^{NTtech}$	NT Sector Technology	IG (0.1, 2)	0.19; 0.03	0.19; 0.03	0.21; 0.03	0.18; 0.03	0.18; 0.03	0.21; 0.02
$100\sigma_M^{PM}$	Import Price Mark-up	IG (0.1, 2)	4.34; 1.03	3.51; 0.80	1.55; 0.20	4.05; 1.06	-	1.80; 0.27
$100\sigma_H^{*PM}$	Export Price Mark-up	IG (0.1, 2)	2.44; 0.25	2.48; 0.26	2.60; 0.27	2.48; 0.25	-	2.81; 0.40
$100\sigma_{WM}$	Wage Cost-Push AR	IG (0.1, 2)	0.35; 0.05	0.35; 0.05	0.37; 0.05	0.35; 0.05	0.37; 0.05	0.35; 0.05
$100\sigma_{IST}$	Investment Specific Technology	IG (0.1, 2)	0.58; 0.07	0.58; 0.07	0.56; 0.07	0.56; 0.06	0.59; 0.07	0.73; 0.10
$100\sigma_{MON}$	Monetary Policy	IG (0.1, 2)	0.20; 0.02	0.20; 0.02	0.20; 0.02	0.19; 0.02	0.22; 0.02	0.19; 0.02
$100\sigma_{TI}$	Consumption Time Impatience	IG (0.1, 2)	0.27; 0.04	0.28; 0.04	0.27; 0.04	0.27; 0.04	0.27; 0.04	0.27; 0.06
$100\sigma^{Y*}$	US Demand (Output)	IG (0.1, 2)	0.06; 0.02	0.06; 0.02	0.07; 0.01	0.06; 0.02	0.06; 0.02	0.05; 0.01
$100\sigma^{CPI*}$	US Price	IG (0.1, 2)	0.31; 0.04	0.30; 0.04	0.34; 0.04	0.31; 0.04	0.31; 0.04	0.31; 0.04
$100\sigma_{MON}^{*}$	US Monetary Policy	IG (0.1, 2)	0.13; 0.01	0.13; 0.01	0.14; 0.02	0.13; 0.01	0.13; 0.01	0.13; 0.01

Note: The technology shocks and import-export price shocks are appropriately rescaled so that they enter the estimation with a unit coefficient, in the same way as the other shocks (which are already presented in rescaled form in the main text). '**Baseline**' indicates the baseline SOE model. '**RExLevel**' indicates the check in which we use the real exchange rate as observable instead of the nominal currency depreciation. '**FixCalvo**' calibrates the price and wage stickiness parameters at lower values. '**PPI**' uses the producer price index to measure tradable goods prices. '**PCP**' imposes the law of one price and does not use import-export price data and shocks. '**No UIP-NEx**' does not use nominal exchange rate data and the UIP shock. B= Beta, IG= Inverse Gamma. P1= Mean and P2= Standard Deviation.

Table 3: Forecast Error Variance Decomposition in Baseline Estimation

VARIABLES →	REAL EXCHANGE RATE			INT. REL. PRICE OF TRADABLES			REL. PRICE OF IMPORTS			REL. PRICE OF NON-TRADABLES			LAW OF ONE PRICE GAP		
HORIZON →	0 Q	8 Q	40 Q	0 Q	8 Q	40 Q	0 Q	8 Q	40 Q	0 Q	8 Q	40 Q	0 Q	8 Q	40 Q
SHOCKS ↓															
Direct Shocks															
UIP	61.48	53.69	42.22	63.32	56.40	43.73	37.33	29.03	19.07	0.07	0.90	2.01	15.96	1.68	0.86
Can. T. Tech	0.12	0.19	0.28	4.10	8.75	7.19	6.12	5.41	3.78	79.89	59.88	46.92	0.07	0.01	0.00
Can. NT. Tech	1.06	3.98	4.22	0.13	0.16	0.27	0.08	0.09	0.14	19.30	32.88	33.18	0.03	0.00	0.00
Can. Import Price	7.16	13.65	18.20	0.91	0.85	2.20	37.59	47.59	54.29	0.02	0.27	2.02	76.27	97.49	98.72
Can. Export Price	2.56	4.08	4.73	3.12	6.82	7.39	2.09	3.69	3.22	0.36	1.95	1.87	0.58	0.06	0.03
Shocks to Marginal Cost															
Can. Wage	0.17	0.66	2.60	0.21	2.03	7.83	0.17	1.29	4.56	0.30	3.32	11.61	0.04	0.00	0.00
Can. Invest.	2.82	1.89	6.69	2.84	2.02	9.72	1.59	0.95	4.95	0.02	0.35	1.30	0.77	0.08	0.04
Shocks to Monetary Policy and Demand															
Can. Mon. Pol.	14.86	12.16	12.30	15.26	12.74	12.60	8.90	6.63	5.91	0.02	0.20	0.47	3.85	0.40	0.21
Can. Consume.	1.16	0.72	0.80	1.21	0.81	0.76	0.69	0.39	0.32	0.00	0.01	0.22	0.32	0.03	0.02
US Shocks															
US GDP	3.80	2.90	3.07	3.86	2.88	3.16	2.27	1.41	1.39	0.02	0.16	0.24	1.00	0.11	0.05
US CPI	1.23	3.31	2.73	1.33	3.49	2.80	1.04	1.95	1.35	0.01	0.08	0.12	0.17	0.03	0.01
US Mon.Pol.	3.57	2.78	2.16	3.70	3.07	2.36	2.14	1.57	1.03	0.00	0.01	0.03	0.94	0.10	0.05

Note: The law of one price gap is essentially the wedge between the international relative price of tradables and the relative price of imports in terms of home-produced tradables. It is not part of the original disaggregation of the real exchange rate given in Equation 28 in the main text. In Table 5, we compare the variance decompositions at a 4 quarter horizon, for all the model specifications we consider. The influence of each shock at forecast horizon k is measured by the variability generated by a unit standard deviation shock at time 0, cumulated over the interval 0 to k. This is then divided by the aggregate variability induced by all the shocks and expressed in percentage terms. We report the mean of a distribution of variance decompositions computed from 150 random draws from the posterior distribution (Each column adds to 100). Confidence bands for the variance decompositions are available on request.

Table 4: Median Impulse Response Functions at a 1 Year Horizon in Model Variants

	Baseline			**RExLevel**			**FixCalvo**			**PPI**			**PCP**			**No UIP-NEx**		
SHOCKS	rer^{NT}	rer^{M}	REx^{CPI}	rer^{NT}	rer^{M}	REx^{CPI}	rer^{NT}	rer^{M}	REx^{CPI}	rer^{NT}	rer^{M}	REx^{CPI}	rer^{NT}	rer^{M}	REx^{CPI}	rer^{NT}	rer^{M}	REx^{CPI}
UIP	**0.04**	**-0.54**	**1.41**	**0.05**	**-0.60**	**1.60**	0.00	**-0.24**	**1.31**	**0.08**	**-0.52**	**1.40**	**0.03**	**-0.50**	**1.33**	-	-	-
Can. T. Tech	**-0.58**	**-0.23**	0.00	**-0.59**	**-0.21**	-0.03	**-0.61**	**-0.33**	**0.20**	**-1.14**	**-0.40**	-0.09	**-0.57**	**-0.33**	**0.27**	**-0.50**	**-0.20**	**-0.16**
Can. NT Tech	**0.43**	0.00	**0.42**	**0.42**	0.00	**0.41**	**0.68**	**-0.04**	**0.81**	**0.44**	0.02	**0.39**	**0.44**	0.02	**0.41**	**0.35**	0.01	**0.27**
Can. Import Price	**0.02**	**-0.65**	**-0.75**	**0.02**	**-0.62**	**-0.64**	0.00	**-1.07**	**-0.95**	**0.03**	**-0.66**	**-0.73**	-	-	-	**0.03**	**-0.78**	**-0.54**
Can. Export Price	**-0.08**	**-0.18**	**0.35**	**-0.08**	**-0.19**	0.42	0.00	**-0.27**	**0.73**	**-0.12**	**-0.15**	**0.26**	-	-	-	**-0.07**	**-0.15**	**0.51**
Can. Wage	**0.09**	**0.07**	-0.08	**0.09**	**0.06**	-0.04	0.00	**0.22**	**-0.58**	**0.16**	0.05	0.03	**0.14**	**0.25**	**-0.49**	**0.07**	**0.02**	**0.13**
Can. Invest.	**-0.03**	0.06	**-0.19**	**-0.03**	0.06	-0.18	0.00	-0.03	-0.02	**-0.05**	**0.09**	**-0.27**	**-0.04**	-0.05	0.11	**-0.01**	0.00	**-0.14**
Can. Mon. Pol.	**-0.02**	**0.24**	**-0.64**	**-0.02**	**0.23**	**-0.60**	0.00	**0.10**	**-0.56**	**-0.03**	**0.22**	**-0.59**	-0.01	**0.36**	**-0.94**	**-0.03**	**0.08**	**-0.56**
Can. Consume.	0.00	**0.06**	**-0.14**	0.00	**0.05**	**-0.13**	0.00	**0.03**	**-0.12**	0.00	**0.05**	**-0.12**	**0.01**	**0.05**	**-0.12**	0.00	**0.03**	**-0.16**
Can.Govt.	**0.02**	**-0.11**	**0.29**	**0.02**	**-0.12**	**0.32**	0.00	**-0.08**	**0.53**	**0.04**	**-0.12**	**0.33**	**0.02**	**-0.08**	**0.24**	**0.04**	**-0.08**	**0.64**
US GDP	**0.01**	**-0.14**	**0.37**	**0.01**	**-0.13**	**0.36**	0.00	**-0.16**	**0.87**	**0.02**	**-0.13**	**0.37**	0.00	**-0.19**	**0.48**	**0.02**	**-0.05**	**0.42**
US CPI	0.00	**-0.12**	**0.31**	0.00	**-0.11**	**0.30**	0.00	**-0.03**	**0.07**	0.00	**-0.11**	**0.29**	0.00	**-0.14**	**0.36**	**0.01**	**-0.05**	**0.31**
US Mon.Pol.	**0.04**	**-0.54**	**1.41**	**0.05**	**-0.60**	**1.60**	0.00	**-0.24**	**1.31**	**0.08**	**-0.52**	**1.40**	**0.14**	**0.25**	**-0.49**	**-0.50**	**-0.20**	**-0.16**

Note: Recall that a positive impulse in any component implies a depreciation effect on the currency. rer^{NT} and rer^{M} are the movements of the relative prices of non-tradables and imports (including the sign and weights in the definition of the real exchange rate) while the aggregate impulse of the real exchange rate is given by REx^{CPI}. The contribution of the international relative price of tradables (not presented) is simply the difference between the aggregate real exchange rate IRF and the two other components. The IRFs are measured in percentage deviations from steady-state. The IRFs significant at a 10% level are marked in bold font while the insignificant IRFs are shaded in gray. '**Baseline**' indicates the baseline SOE model. '**RExLevel**' indicates the check in which we use the real exchange rate as observable instead of the nominal currency depreciation. '**FixCalvo**' calibrates the price and wage stickiness parameters at lower values. '**PPI**' uses the producer price index to measure tradable goods prices. '**PCP**' imposes the law of one price and does not use import-export price data and shocks. '**No UIP-NEx**' does not use nominal exchange rate data and the UIP shock.

Table 5: Variance Decomposition of the Real Exchange Rate at a 1 Year Horizon in Model Variants

	Baseline	**RExLevel**	**FixCalvo**	**PPI**	**PCP**	**No UIP-NEx**
SHOCKS						
UIP	55.72	64.93	43.47	56.97	48.53	-
Can. T. Tech	0.15	0.17	0.84	0.65	1.97	1.60
Can. NT. Tech	3.30	2.72	7.43	2.81	4.01	2.57
Can. Import Price	12.16	7.84	11.19	12.44	-	14.09
Can. Export Price	3.49	3.68	6.06	1.89	-	12.68
Can. Wage	0.35	0.27	3.51	0.25	5.70	1.87
Can. Invest.	2.14	1.66	0.55	3.27	0.47	2.85
Can. Mon. Pol.	12.52	10.11	10.16	11.17	26.14	22.94
Can. Consume	0.87	0.65	0.51	0.79	0.93	2.68
US GDP	3.33	3.36	5.76	3.77	2.55	23.30
US CPI	3.07	2.31	9.90	3.12	5.64	8.55
US Mon.Pol.	2.92	2.30	0.62	2.85	4.05	6.86

Note: The influence of each shock at forecast horizon k is measured by the variability generated by a unit standard deviation shock at time 0, cumulated over the interval 0 to k. This is then divided by the aggregate variability induced by all the shocks and expressed in percentage terms. For each specification, we report the mean of a distribution of variance decompositions computed from 150 random draws from the posterior distribution. Each column adds to 100. '**Baseline**' indicates the baseline SOE model. '**RExLevel**' indicates the check in which we use the real exchange rate as observable instead of the nominal currency depreciation. '**FixCalvo**' calibrates the price and wage stickiness parameters at lower values. '**PPI**' uses the producer price index to measure tradable goods prices. '**PCP**' imposes the law of one price and does not use import-export price data and shocks. '**No UIP-NEx'** does not use nominal exchange rate data and the UIP shock.