RESERVE BANK OF NEW ZEALAND

DP2005/06

A Simple, Structural, and Empirical Model of the Antipodean Transmission Mechanism

Thomas A. Lubik

December 2005

JEL classification: C11, C51, C52, E58

www.rbnz.govt.nz/research/discusspapers/

Discussion Paper Series

DP2005/06

A Simple, Structural, and Empirical Model of the Antipodean Transmission Mechanism*

Thomas A. Lubik†

Abstract

This paper studies the transmission of business cycles and the sources of economic fluctuations in Australia and New Zealand by estimating a Bayesian DSGE model. The theoretical model is that of two open economies that are tightly integrated by trade in goods and assets. They can be thought of as economically large relative to each other, but small with respect to the rest of the world. The two economies are hit by a variety of country-specific and world-wide shocks. The main findings are that the pre-eminent driving forces of Antipodean business cycles are worldwide technology shocks and foreign, ie rest-of-the-world, expenditure shocks. Domestic technology shocks and monetary policy shocks appear to play only a minor role. Transmission of policy shocks is asymmetric, and neither central bank is found to respond to exchange rate movements. The model can explain 15 percent of the observed exchange rate volatility.

* The views expressed in this paper are those of the author(s) and do not necessarily reflect those of the Reserve Bank of New Zealand. This paper was prepared for the 2005 Reserve Bank of New Zealand DSGE Workshop. Much of the research contained therein was conducted while the author was visiting the Economics Department of the RBNZ, for whose hospitality the author is extremely grateful. Special thanks go Aaron Drew, Ozer Karagedikli, Kirdan Lees, Grant Spencer, and Shaun Vahey. The author also likes to thank seminar participants at the University of Canterbury for useful comments.

† Address: Department of Economics, Johns Hopkins University, Mergenthaler Hall, 3400 N. Charles Street, Baltimore, MD 21218, USA. Tel.: +1 410 516 5564, Fax: +1 410 516 7600. *email address: thomas.lubik@jhu.edu.*

1 Introduction

This paper studies the transmission of business cycles and the sources of economic fluctuations in Australia and New Zealand. It does so by estimating a fully specified, optimization-based dynamic stochastic general equilibrium (DSGE) model using a Bayesian approach. This paper thus builds on and extends a growing research area of Bayesian estimation of open economy models that started with Lubik and Schorfheide (2003). The theoretical model is that of two open economies that are tightly integrated by trade in goods and assets. They can be thought of as economically large relative to each other, but small with respect to the rest of the world. The two economies are hit by a variety of country-specific and world-wide shocks. The presence of nominal rigidities motivates the use of monetary policy as a stabilization tool. The Bayesian estimation approach treats the theoretical model as the data-generating process for the observed time series. The estimation takes full advantage of the cross-equation restrictions implied by the model to achieve identification.

The main findings of the paper are that the pre-eminent driving forces of Antipodean business cycles are worldwide technology shocks and foreign, ie rest-of-the-world, expenditure shocks. Domestic technology shocks and monetary policy shocks appear to play only a comparatively minor role. This result goes hand in hand with the observation that these latter, country-specific shocks exhibit quantitatively insignificant transmission. From a qualitative point of view, however, transmission is asymmetric: for instance, a monetary contraction in New Zealand increases output growth in Australia, but the opposite effect occurs in the other direction. The asymmetric transmission mainly stems from the monetary policy behaviour in each country, as the Reserve Bank of Australia (RBA) shows considerably larger concern for output growth targeting than its New Zealand counterpart, the RBNZ. Perhaps surprisingly, neither central bank responds consistently to exchange rates. Finally, the structural estimation reveals that the model can explain roughly 15 percent of bilateral exchange rate movements. This seemingly small number is, in fact, towards the higher end of the empirical literature and reflects more of a shortcoming of the current international finance literature.

The empirical literature on business cycle fluctuations in Australasia parallels that of North America and Europe. The literature can be divided into two strands: time-series studies using structural or non-structural vector autoregressions (VARs), and calibration studies using theoretical models. The VAR approach typically uses recursive ordering of innovations and/or contemporaneous (and sometimes long-run) restrictions to achieve identification. For instance, a recursive ordering of shocks makes use of the assumption that domestic shocks in small open economies have no effects on world shocks. Similarly, contemporaneous restrictions posit short-run delays in the transmission of macroeconomic shocks. This approach has been used by, amongst other, Dungey and Pagan (2000) and Buckle et al. (2002) to study the determinants of business cycles and the effects of monetary policy shocks in Australia and New Zealand, respectively.

An alternative methodology is the calibration approach to DSGE models. This methodology starts out with the construction of a fully specified structural model, where the equations in the model are derived from the intertemporal optimization problems of economic agents. The structural parameters of the model are chosen to match first, and sometimes second, moments of business cycle statistics of interest. The model is then simulated and its time-series predictions are compared to actual, observed data. The calibrated model is considered to be an approximation to the true data-generating process, and hence is used to identify various shock processes and their transmission mechanisms.

The unifying feature of these different methodologies is that the results differ considerably across studies, which may to a large extent be attributed to the type of methodology used. In this paper, I therefore depart from the existing literature by utilizing an *estimated* DSGE model. This can be thought of as an intermediate methodological approach to the ones previously discussed. Instead of calibrating the structural parameters, I estimate the model which has the advantage that it explicitly takes into consideration the uncertainty surrounding the values of the structural parameters. In addition, structural estimation allows me to take full advantage of the cross-equation restrictions implied by the model to achieve identification. In contrast, studies that employ VARs typically only make use of some, but not all, of the restrictions implied by economic theories.

The Antipodean economies have previously been analyzed in a Bayesian DSGE framework by Lubik and Schorfheide (2003); they estimate a small open economy model in the New Open Economy Macroeconomics mould following Galí and Monacelli (2005). Lubik and Schorfheide find that neither the RBA nor the RBNZ directly respond to the exchange rate, not even during episodes when it was stated policy, such as the period in which the RBNZ targeted a monetary conditions index (MCI), prior to 1999. Moreover, exchange rate movements are largely driven by foreign inflation, while the terms of trade do not play a role at all.[1] In

[1] The lack of the terms of trade in driving exchange rates is also confirmed by Lubik and Teo (2005) in an estimated international real business cycle model.

a follow-up paper that allows for imperfect pass-through, Lubik (2005) confirms these results although the methodology and treatment of data differ slightly.

Justiniano and Preston (2004) also analyze these two countries and find that imperfect pass-through and habit formation are important in capturing the behaviour of aggregate variables. More recently, research at the RBNZ (Liu, 2005, and Santacreu, 2005) is concerned with developing and estimating an empirically viable DSGE model that can be used for forecasting and policy evaluation purposes.

None of these papers, however, studies the transmission of business cycle fluctuations across the Tasman Sea. This issue is of importance for the conduct of policy since Australia is at once New Zealand's largest trading partner and arguably her main competitor in export markets. Because of their close economic and geographic proximity, I assume both economies are well-integrated, to the extent that their terms of trade become fully endogenous with respect to each other. Moreover, both countries are likely to be hit by the same external shocks, but can be affected differently. In order to analyze how this affects business cycle fluctuations in the Antipodes, I build a two-country model that is small relative to the rest of the world, which is left largely unspecified. The specification of the model follows Lubik and Schorfheide (2005).

The rest of the paper is organized as follows. In the next section, I present the theoretical model. Section 3 contains a discussion of the Bayesian estimation approach and a description of the data and the choice of the prior distribution. In section 4 I present the estimation of the benchmark, most-unrestricted model, including a discussion of the parameter estimates, the impulse responses, and variance decompositions. Section 5 presents a few robustness checks – in particular examining the effects of changing the priors – further assesses whether the Reserve Banks respond directly to the exchange rate, and identifies sources of economic fluctuations.

2 An empirical model of Australia and New Zealand

I develop a model of the transmission of business cycles between Australia and New Zealand. The theoretical model is based on Lubik and Schorfheide (2005) who extend the framework in Monacelli (2005) to a two-country setting. I explicitly allow for endogenous deviations from purchasing power parity in the short-run, but not in the long-run. Producers are assumed to set prices monopolistically for the domestic and the world markets; prices are set in the producers' own currency. Imported goods, however, are subject to price discrimination as monopolistic importers charge a mark-up to consumers at the border. This implies that the same good can have different prices depending on where it is sold even after adjusting for exchange rate movements.

Preferences and technologies are assumed to be symmetric, but there are country-specific differences in price-setting, policy rules, and exogenous shocks. I also assume the existence of an exogenous, rest-of-the world sector, that is largely left unspecified. It is designed to capture world-wide disturbances that can affect both economies. Under the assumption of perfect risk sharing the model has a manageable reduced form, but can allow for potentially rich exchange rate behaviour. In terms of notation, I denote the origin of goods produced in New Zealand (Australia) with a subscript NZ (AU), while the *location* of economic activities is indexed by a '*' for Australia, and no index for New Zealand. For instance, C_{NZ} is the consumption of the New Zealand-produced good in New Zealand, while (C^*_{AU}) is the Australian consumption of the Australian-produced good. For the purposes of this paper, I also interpret New Zealand as the home, domestic economy.

2.1 Domestic households

The domestic economy, ie New Zealand, is populated by a continuum of households whose preferences are described by an intertemporal utility function:[2]

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t \left[\frac{(\mathscr{C}_t / A_{W,t})^{1-\tau}}{1-\tau} - N_t \right] \right], \tag{1}$$

where $\mathscr{C}_t = C_t - h\gamma C_{t-1}$ is effective consumption under habit formation and N_t is labour input. Habits are internalized by the household, with $0 \leq h \leq 1$ being the habit persistence parameter. $\tau > 0$ is the coefficient of relative risk aversion, and $0 < \beta < 1$ is the discount factor. $A_{W,t}$ is a non-stationary world-wide technology shock; define $z_t = A_{W,t}/A_{W,t-1}$. The steady state growth rate of $A_{W,t}$ is γ. The presence of the term $A_{W,t}$ in (1) implies that households derive utility from effective consumption relative to the level of technology and guarantees that the model has a balanced growth path along which hours worked are stationary even if $\tau \neq 1$.

[2] We ignore household-specific indices for notational convenience.

C_t is an aggregate consumption index:

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{NZ,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{AU,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \tag{2}$$

where $0 \leq \alpha < 1$ is the share of aggregate consumption falling on imports; and $\eta > 0$ is the intratemporal substitution elasticity between home and foreign consumption goods. Households allocate aggregate expenditure based on the demand functions:

$$C_{NZ,t} = (1-\alpha)\left(\frac{P_{NZ,t}}{P_t}\right)^{-\eta} C_t \text{and } C_{AU,t} = \alpha\left(\frac{P_{AU,t}}{P_t}\right)^{-\eta} C_t. \tag{3}$$

$P_{NZ,t}$, $P_{AU,t}$ are domestic and foreign goods price indices, and

$$P_t = \left[(1-\alpha) P_{NZ,t}^{1-\eta} + \alpha P_{AU,t}^{1-\eta} \right]^{\frac{1}{1-\eta}}, \tag{4}$$

is the consumption-based price index (CPI).[3]

In the aggregate, households face the budget constraint:

$$P_{NZ,t}C_{NZ,t} + P_{AU,t}C_{AU,t} + E_t[Q_{t,t+1}D_{t+1}] \leq W_t N_t + D_t - T_t, \tag{5}$$

where W_t is the nominal wage for labour services provided to firms. $Q_{t,t+1}$ is the stochastic discount factor used for evaluating consumption streams and D_t represents payments from a portfolio of assets, so that $E_t[Q_{t,t+1}D_{t+1}]$ corresponds to the value of portfolio purchases at time t. Under the assumption of complete asset markets, both domestically and internationally, this portfolio comprises a complete set of state-contingent claims. T_t are lump-sum taxes imposed by the government to finance its purchases.

Households maximize the intertemporal utility function subject to a sequence of budget constraints for all t. The labour-leisure choice is governed by the intratemporal optimality condition $\lambda_t^{-1} = W_t/P_t$, where λ_t is the marginal utility of income.

[3] Each domestic- and foreign-produced goods aggregate is composed of differentiated individual products with demand functions:

$$C_{NZ,t}(i) = \left(\frac{P_{NZ,t}(i)}{P_{NZ,t}}\right)^{-\omega} C_{NZ,t} \text{ and } C_{AU,t}(i) = \left(\frac{P_{AU,t}(i)}{P_{AU,t}}\right)^{-\omega} C_{AU,t}$$

and associated price indexes. I abstract from this level of disaggregation since it is immaterial to our aggregate model specification. Specifically, the substitution elasticity ω does not appear in the linearized model.

Intertemporal consumption choice is given by:

$$A_{W,t}\lambda_t P_t = \mathscr{C}_t^{-\tau} - h\gamma\beta E_t\left[\frac{A_{W,t}}{A_{W,t+1}}\mathscr{C}_{t+1}^{-\tau}\right], \tag{6}$$

while optimal portfolio choice implies:

$$Q_{t,t+1} = \beta\frac{\lambda_{t+1}}{\lambda_t}\frac{P_{t+1}}{P_t}. \tag{7}$$

This relationship can be used to construct the return on nominal government bonds, ie the nominal interest rate:

$$R_t^{-1} = \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\frac{P_{t+1}}{P_t}\right], \tag{8}$$

which is assumed to be the monetary authority's instrument variable.

2.2 Domestic producers

Domestic differentiated goods are produced by a continuum of monopolistically competitive producers which are subject to Calvo-type price setting. Each period a fraction $1-\theta_{NZ}$ of domestic firms set prices optimally, while θ_{NZ} firms adjust prices in accordance with the steady state inflation rate π, which is common to the home and the foreign economy. Each firm $j \in [0,1]$ maximizes discounted intertemporal profits subject to a downward-sloping demand curve. Demand for a firm's product derives both from domestic sources $C_{NZ,t}$ as well as from abroad $C^*_{NZ,t}$. Additionally, there is demand arising from consumers in the rest of the world, $C^{ROW}_{NZ,t}$, where I assume for simplicity that they share the preferences of Antipodean consumers, so that demand has the same functional form. Rest-of-the-world demand is specified as an exogenous and stationary AR(1) process. Moreover, I assume that firms do not engage in local currency pricing; that is, prices are set only with regard to domestic demand considerations.

Firms have access to a linear production technology that uses labour as its only input:

$$Y_{NZ,t}(j) = A_{W,t}A_{NZ,t}N_t(j), \tag{9}$$

where $A_{NZ,t}$ is a stationary and country-specific technology shock. Firms that are allowed to re-optimize their price in period T maximize:

$$E_T\left[\sum_{t=T}^{\infty}\theta_{NZ}^{t-T}Q_{T,t}Y_{NZ,t}(j)\left[P_{NZ,T}(j)\pi^{t-T} - P_{NZ,t}MC_{NZ,t}\right]\right], \tag{10}$$

with respect to $P_{NZ,T}(j)$ subject to the demand function:

$$Y_{NZ,t}(j) = \left(\frac{P_{NZ,t}(j)}{P_{NZ,t}}\right)^{-\omega} \left(C_{NZ,t} + C^{*}_{NZ,t} + C^{ROW}_{NZ,t}\right), \tag{11}$$

where $MC_{NZ,t} = W_t / P_{NZ,t}$ is common to all producers due to perfectly competitive labour markets. Firms evaluate revenue streams by the households' stochastic discount factor $Q_{T,t}$. θ_{NZ}^{t-T} is the probability that the specific firm will not be allowed to adjust its price between periods T and t. The solution to the domestic firm's optimization problem implies that prices are set as a (time-varying) mark-up over marginal cost. This results in the familiar Phillips-curve relationship between domestic inflation and marginal cost after aggregation over individual firms and imposing ex-post homogeneity.

2.3 Domestic importers

In the vein of Monacelli (2005) I assume that endogenous deviations from PPP in the short run arise due to the existence of monopolistically competitive importers. Domestic consumers are required to purchase foreign-produced goods from importers that exert market power. Importers purchase foreign goods at world-market prices $P^{*}_{F,t}(j)$ (which are set by their respective producers in their own currency), so that the law of one price holds at the border. Importers then sell these goods to domestic consumers and charge a mark-up over their cost, which creates a wedge between domestic and import prices of foreign goods when measured in the same currency.

It is useful to define the endogenous deviations from PPP, the law of one price (LOP) gap as follows:

$$\psi_{AU,t} = \frac{e_t P^{*}_{AU,t}}{P_{AU,t}}, \tag{12}$$

where e_t is the nominal exchange rate, defined as domestic currency per foreign currency unit (eg NZD/AUD). If PPP holds, then $\psi_{AU,t} \equiv 1$. With positive importer markups $\psi_{AU,t} < 1$. Pass-through from exchange rate movements to the domestic currency prices of imports is imperfect as importers adjust their pricing behaviour to extract optimal revenue from consumers.

Similar to domestic producers, importers operate under Calvo-style price-setting, with $1 - \theta_{AU}$ importers setting prices optimally each period. Importers maximize the discounted stream of expected profits:

$$E_T\left[\sum_{t=T}^{\infty}\theta_{AU}^{t-T}Q_{T,t}C_{AU,t}(j)\left[P_{AU,T}(j)\pi^{t-T}-e_tP_{AU,t}^{*}(j)\right]\right], \tag{13}$$

subject to the demand function:

$$C_{AU,t}(j)=\left(\frac{P_{AU,t}(j)}{P_{AU,t}}\right)^{-\omega}C_{AU,t}. \tag{14}$$

Note that the marginal cost of purchasing imports is the LOP gap for the specific good. Consequently, importers set domestic currency prices of foreign goods as a (time-varying) mark-up over $1/\psi_{F,t}$.

This arrangement can be intuitively thought of in two ways. Exporters deliver their differentiated products to a supra-national warehouse from which delivery of indexed goods is executed. Alternatively, goods produced for export are bundled, shipped across borders, and then broken apart by importers. It is important to point out that there exists a correspondence between identically indexed goods produced abroad and imported without producers and importers being aware of it. Producers (exporters) are necessarily ignorant of the pricing markup introduced by importers. If this were not the case then the pricing decisions by exporters would not optimal.[4] It can be shown that the endogenous deviations from PPP then result in a Phillips-curve relationship between import-price inflation and the LOP gap.

2.4 The foreign economy

Home and foreign economies are assumed to be symmetric in terms of preferences and technology, but they can differ in terms of price-setting and monetary policy decisions. The equations describing the foreign, Australian economy are therefore the same as for New Zealand, with 'starred' variables and parameters properly substituted.

It is convenient to define the real exchange rate as:

$$s_t=\frac{e_tP_t^{*}}{P_t}. \tag{15}$$

[4] I am grateful to Luca Dedola for pointing this out.

Symmetry implies that the foreign real exchange rate $s_t^* = s_t^{-1}$. On the other hand, the terms of trade differ between the two countries by the LOP gaps. The domestic terms of trade, that is, the price of exports in terms of imports measured in domestic currency are

$$q_t = \frac{P_{NZ,t}}{P_{AU,t}}, \tag{16}$$

while the foreign terms of trade are:

$$q_t^* = \frac{P^*_{AU,t}}{P^*_{NZ,t}}. \tag{17}$$

(Lowercase q_t is not to be confused with the $Q_{T,t}$ notation used for the stochastic discount factor.) Using the definition of the real exchange rates the following expression can be derived:

$$\frac{\psi_{AU,t}}{q_t} = \frac{\psi^*_{NZ,t}}{q_t^*}. \tag{18}$$

Home and foreign terms of trade coincide (inversely) only when pass-through is perfect. With imperfect pass-through differential pricing decisions across countries affect each countries terms of trade with possibly different effects on output. Additionally, this allows for potentially richer international price dynamics to account for real exchange rate movements.

2.5 Risk-sharing, market clearing and equilibrium

Two further equations are required to close the emodel. Complete international asset markets imply perfect risk-sharing between households in the two countries. In equilibrium, stochastic discount factors in the two countries have to be equalized, which leads to the following condition (see Chari, Kehoe and McGrattan, 2002, or Gali and Monacelli, 2004, for further discussion):

$$\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} = Q_{t,t+1} = \beta \frac{\lambda^*_{t+1}}{\lambda^*_t} \frac{P^*_t}{P^*_{t+1}} \frac{e_t}{e_{t+1}}. \tag{19}$$

Goods market clearing requires that:

$$Y_{NZ,t} = C_{NZ,t} + C^*_{NZ,t} + C^{ROW}_{NZ,t} \text{ and } Y^*_{AU,t} = C_{AU,t} + C^*_{AU,t} + C^{ROW}_{AU,t}. \tag{20}$$

I impose the restriction that Australia's economy is five times the size of New Zealand's, and that 25 percent (10 percent) of New Zealand (Australian) exports go to the other country. The remaining exports are soaked up by the (unspecified) rest of the world. I do not estimate these parameters as they pertain purely to levels. Moreover, I assume that initial net foreign asset positions are zero. This implies balanced trade in value terms in the steady state and no net asset accumulation by any country. While this is somewhat restrictive it substantially facilitates computation.

2.6 The Linearized Model

I proceed by (log-) linearizing the relevant model equations around the balanced growth path. The model imposes common steady state real interest rates, inflation rates, growth rates, and technologies. Since the model contains a non-stationary component in the form of world-wide productivity growth, I detrend the affected variables by their specific growth components beforehand. All variables with tildes are in log-deviations from the steady state: $\widetilde{x}_t = \log x_t - \log \bar{x}$.

The rest of this section discusses the key structural equations. A linear approximation to the solution of the domestic firms' price-setting problems results in a Phillips-curve type relationship between domestic inflation and marginal cost:

$$\widetilde{\pi}_{NZ,t} = \beta E_t \widetilde{\pi}_{NZ,t+1} + \kappa_{NZ} \widetilde{mc}_t, \tag{21}$$

where $\kappa_{NZ} = \frac{1-\theta_{NZ}}{\theta_{NZ}}(1-\theta_{NZ}\beta)$. Using the condition for labour-leisure choice, the marginal cost term can be expressed as $\widetilde{mc}_t = -\widetilde{\lambda}_t - \alpha\widetilde{q}_t - \widetilde{A}_{NZ,t}$. $\widetilde{\lambda}_t$ is the marginal utility of income, which evolves according to:

$$-\widetilde{\lambda}_t = \frac{\tau}{1-h\beta}\widetilde{\mathscr{C}}_t - \frac{h\beta}{1-h\beta} E_t[\tau\widetilde{C}_{t+1} + \widetilde{z}_{t+1}], \tag{22}$$

where the law of motion for the habit stock is given by:

$$(1-h)\widetilde{\mathscr{C}}_t = \widetilde{C}_t - h\widetilde{C}_{t-1} + h\widetilde{z}_t. \tag{23}$$

For $h = 0$, this reduces to standard consumption preferences. Recall that $\widetilde{z}_t = \Delta\widetilde{A}_{W,t}$. World-wide shocks do not affect marginal costs (only country-specific shocks do), but they change the intertemporal consumption trade-off as evidenced by habit dynamics and the Euler-equation:

$$-\widetilde{\lambda}_t = -E_t\widetilde{\lambda}_{t+1} - (\widetilde{R}_t - E_t\widetilde{\pi}_{t+1}) + E_t\widetilde{z}_{t+1}. \tag{24}$$

The price-setting problem of importers reduces to a Phillips-curve type relation between import price inflation and the LOP gap:

$$\widetilde{\pi}_{AU,t} = \beta E_t \widetilde{\pi}_{AU,t+1} + \kappa_{AU} \widetilde{\psi}_{AU,t}, \tag{25}$$

where $\kappa_{AU} = \frac{1-\theta_{AU}}{\theta_{AU}} (1 - \theta_{AU} \beta)$. CPI-inflation can be derived using the definition:

$$\widetilde{\pi}_t = \alpha \widetilde{\pi}_{AU,t} + (1-\alpha) \widetilde{\pi}_{NZ,t}, \tag{26}$$

and the terms of trades evolve according to:

$$\widetilde{q}_t = \widetilde{q}_{t-1} + \widetilde{\pi}_{NZ,t} - \widetilde{\pi}_{AU,t}. \tag{27}$$

Inflation dynamics therefore depend on domestic driving forces as well as international relative price movements and endogenous deviations from PPP in the form of imperfect pass-through. The real exchange rate behaves according to:

$$\widetilde{s}_t = \widetilde{\psi}_{AU,t} - (1-\alpha) \widetilde{q}_t - \alpha \widetilde{q}_t^*, \tag{28}$$

which captures the distortions introduced by the LOP gap as well as movements in each country's own terms of trade. Using the definition of the real exchange rate also allows derivation of nominal exchange rate dynamics:

$$\Delta \widetilde{e}_t = \widetilde{\pi}_t - \widetilde{\pi}_t^* + \Delta \widetilde{s}_t. \tag{29}$$

The (linearized) asset pricing equation for nominal bonds implies that the interest rate differential is related to expected exchange rate depreciation, in other words, uncovered interest parity (UIP):

$$\widetilde{R}_t - \widetilde{R}_t^* = E_t \Delta \widetilde{e}_{t+1}. \tag{30}$$

Furthermore international risk-sharing implies a relationship between marginal utilities across countries adjusted for purchasing power:

$$\widetilde{\lambda}_t = \widetilde{\lambda}_t^* - s_t. \tag{31}$$

The goods market clearing condition:

$$\widetilde{y}_{H,t} = \widetilde{c}_t - \widetilde{c}_{NZ,t}^{ROW} - \frac{\alpha}{\tau} \widetilde{s}_t - \alpha(1-\alpha)\eta \left(\widetilde{q}_t - \widetilde{q}_t^*\right), \tag{32}$$

shows how output is affected by demand and relative prices. Demand disturbances in the form of foreign shocks $\widetilde{c}_{NZ,t}^{ROW}$ affect output directly and not via changing marginal rates of substitution in consumption and leisure.

The model is closed by specifying monetary policy. I assume that central banks in both countries adjust the nominal interest in response to deviations of inflation, output growth, and exchange rate depreciation from their respective targets:

$$\widetilde{R}_t = \rho_R \widetilde{R}_{t-1} + (1-\rho_R)\left[\psi_1 \widetilde{\pi}_t + \psi_2(\Delta\widetilde{y}_t + \widetilde{z}_t) + \psi_3 \Delta\widetilde{e}_t\right] + \varepsilon_{R,t}. \tag{33}$$

The monetary policy rule is of the standard Taylor-type with the exception that the central bank responds to deviations of output growth from the mean growth rate γ, instead of a measure of the output gap.

Once the equations describing the foreign economy are added, the log-linearized model consists of 21 equations in endogenous variables, and 5 equations describing the evolution of the exogenous autoregressive shocks:

$$\begin{aligned}
\widetilde{z}_t &= \rho_z \widetilde{z}_{t-1} + \varepsilon_{z,t}, \qquad (34)\\
\widetilde{A}_t &= \rho_A \widetilde{A}_{t-1} + \varepsilon_{A,t},\\
\widetilde{A}^*_t &= \rho_{A^*} \widetilde{A}^*_{t-1} + \varepsilon_{A^*,t},\\
\widetilde{c}^{ROW}_{NZ,t} &= \rho_{NZ} \widetilde{c}^{ROW}_{NZ,t-1} + \varepsilon_{NZ,t},\\
\widetilde{c}^{ROW}_{AU,t} &= \rho_{AU} \widetilde{c}^{ROW}_{AU,t-1} + \varepsilon_{AU,t}.
\end{aligned}$$

Moreover, there are innovations in each country's monetary policy rule denoted by $\varepsilon_{R,t}$ and $\varepsilon_{R^*,t}$. Given these exogenous process the model is then solved using the methods described in Sims (2002).

3 Empirical approach

3.1 Bayesian estimation

Let y_t be the vector of observables and $Y^T = \{y_1, \ldots, y_T\}$. The parameters of the structural model are collected in the vector θ. The log-linearized DSGE model can be written as a linear rational expectations (LRE) system of the form:

$$\Gamma_0(\theta)s_t = \Gamma_1(\theta)s_{t-1} + \Gamma_\varepsilon(\theta)\varepsilon_t + \Gamma_\eta(\theta)\eta_t, \tag{35}$$

where s_t denotes the vector of model variables such as $\widetilde{y}_t$, $\widetilde{\pi}_t$, $\widetilde{R}_t$. The vector ε_t stacks the innovations of the exogenous processes and η_t is composed of rational expectations forecast errors.[5] The dynamics of the exogenous shock processes are

[5] For instance, one can define $\eta^c_t = \widetilde{c}_t - \boldsymbol{E}_{t-1}[\widetilde{c}_t]$ and absorb $\boldsymbol{E}_t[\widetilde{c}_{t+1}]$ to represent the model developed above in terms of (35).

absorbed in the definition of the Γ matrices. The solution to (35) can be expressed as:

$$s_t = \Phi_1(\theta)s_{t-1} + \Phi_\varepsilon(\theta)\varepsilon_t. \tag{36}$$

A measurement equation can then be used to relate the model variables s_t to the observables vector y_t:

$$y_t = A(\theta) + Bs_t. \tag{37}$$

In the empirical application y_t is composed of output growth, inflation, and nominal interest rates for the New Zealand and Australia, as well as their bilateral exchange rate. B does not depend on θ as it merely selects elements of s_t. $A(\theta)$ captures the mean of y_t, which is related to the underlying structural parameters. The often encountered practice of demeaning the data prior to estimation thus removes information on the objects of interest in the estimation exercise, namely the structural parameters, and should therefore be avoided.

The linearized DSGE model thus provides a state-space representation for y_t. Under the assumption that all the structural shocks are normally distributed and uncorrelated over time, a likelihood function $L(\theta|Y^T)$ can be obtained and evaluated using the Kalman filter. In what follows I adopt a Bayesian approach and place a prior distribution with density $p(\theta)$ on the structural parameters. The data Y^T are used to update the prior through the likelihood function. According to Bayes Theorem the posterior distribution of θ is of the form

$$p(\theta|Y^T) = \frac{L(\theta|Y^T)p(\theta)}{\int L(\theta|Y^T)p(\theta)d\theta}. \tag{38}$$

Draws from the posterior can be generated through Bayesian simulation techniques described in more detail in Lubik and Schorfheide (2005). Posterior draws of impulse response functions and variance decompositions can be obtained by transforming the θ draws accordingly.

In the subsequent empirical analysis one question of interest is the hypothesis that central banks do not react systematically to exchange rate movements. In the context of the reaction function specification this corresponds to $H_0 : \psi_3 = 0$. Let $\pi_{0,0}$ be the prior probability associated with this hypothesis. The posterior odds of H_0 versus $H_1 : \psi_3 > 0$ are given by:[6]

$$\frac{\pi_{0,T}}{\pi_{1,T}} = \left(\frac{\pi_{0,0}}{\pi_{1,0}}\right)\left(\frac{p(Y^T|H_0)}{p(Y^T|H_1)}\right). \tag{39}$$

The first factor is the prior odds ratio in favor of $\psi_3 = 0$. The second term is called the Bayes factor and summarizes the sample evidence in favor of H_0. The term $p(Y^T|H_i)$ is called the Bayesian data density and is defined as

$$p(Y^T|H_i) = \int L(\theta|Y^T, H_i)p(\theta|H_i)d\theta. \tag{40}$$

The logarithm of the marginal data density can be interpreted as maximized log-likelihood function penalized for model dimensionality, see, for instance, Schwarz (1978). The marginal data density (40) is approximated by using a numerical technique known as modified harmonic mean estimation. In general, this procedure can be used to sequentially test for the relative fit of different model specifications, as well as the fit of a structural DSGE model relative to a reference such as a VAR. The marginal data density incorporates a penalty for overparameterization and thus does not necessarily favor richer, more 'realistic' modelling frameworks. This usage of Bayesian posterior odds testing has, however, been recently criticized by Sims (2004) who argues that it is highly sensitive to seemingly innocuous model specification choices such as detrending or demeaning. Nevertheless, the marginal data density is an informative statistic on how well a specific model describes the observed time series behaviour.

3.2 Data description and choice of the prior

The model is fitted to New Zealand and Australian data on output growth, inflation, nominal interest rates and bilateral exchange rate changes. The data are seasonally adjusted and are at quarterly frequencies for the period 1991:Q1 to 2004:Q4. Although data are available for the 1980s, this decade, particularly in New Zealand, was characterized by several structural changes in the conduct of monetary and fiscal policy that markedly affected aggregate time series behaviour. Attempts to fit the model to the full sample were largely unsuccessful.

[6] According to Jeffreys (1961) the posterior odds may be interpreted as follows: $\pi_{0,T}/\pi_{1,T} > 1$ null hypothesis is supported; $1 > \pi_{0,T}/\pi_{1,T} > 10^{-1/2}$ evidence against H_0 but not worth more than a bare mention; $10^{-1/2} > \pi_{0,T}/\pi_{1,T} > 10^{-1}$ substantial evidence against H_0; $10^{-1} > \pi_{0,T}/\pi_{1,T} > 10^{-3/2}$ strong evidence against H_0; $10^{-3/2} > \pi_{0,T}/\pi_{1,T} > 10^{-2}$ very strong evidence against H_0; $10^{-2} > \pi_{0,T}/\pi_{1,T}$ decisive evidence against H_0.

The data series were obtained from the Reserve Bank of New Zealand.[7] The output series is real per-capita gross domestic product (per capita GDP) in first differences. Inflation is computed using the CPI. The nominal interest rate is a short-term rate for each country, while the exchange rate variable is simply the bilateral nominal exchange rate in first differences.

Priors for the structural parameters are chosen based on several considerations. Table 1 provides information about the distributions, means and 90 percent coverage regions. Prior distributions are assumed to be independent. Size restrictions on the parameters, such as non-negativity, are implemented either by truncating the distribution or properly redefining the parameters to be estimated. Since the solution of the linear rational expectations model may be non-existent or exhibit multiple equilibria, I truncate the joint prior distribution at the boundary of the determinacy region. The benchmark prior assigns about 3 percent probability to indeterminacy. Mean and confidence intervals are then calculated for the truncated version of the prior.

The parameters associated with price stickiness – the θ parameters in my notation – are of particular interest in the New Keynesian framework since they are closely tied to the trade-off between inflation and output stabilization. However, as emphasized by Lubik and Schorfheide (2005), the θ's are often difficult to assess and interpret empirically. I therefore assign fairly loose priors to these parameters centered at 0.5 with a standard deviation of 0.15. Other studies of the Antipodean economies tend to find higher degrees of rigidity (especially Santacreu, 2005). These findings are, by necessity, model dependent, and I assess the robustness of the estimates to more agnostic prior specifications below.

The prior for the import share α is tightly centered at 0.3 based on actual trade patterns in these economies. I choose a mean of 0.3 for the habit persistence parameter h, which is at the low end of values used in the literature. Habit preferences are introduced to capture some of the persistence in the data. Since the model specification already imposes strong persistence in terms of the common trend, this lower value can be justified on a priori grounds. Furthermore, the coefficient of relative risk aversion τ is set at a mean value of 2.0. Finally, intratemporal substitution elasticities are often hard to pin down. I again take a somewhat agnostic route and set the prior mean at 1.0 with a large standard deviation of 0.50.

The priors for the monetary policy coefficients ψ_1 and ψ_2 (and their Australian counterparts) are centered at the values commonly associated with the Taylor-rule,

[7] Special thanks go to Kirdan Lees for help with the data.

1.50 and 0.50, respectively. Previous studies have suggested that these parameters are slightly larger (Liu, 2005) or substantially larger (Lubik and Schorfheide, 2003) than these values. Since specifications of the policy rule as well as exogenous driving processes differ across these studies, I choose conservative priors but with fairly wide confidence intervals. I also allow for the possibility of an interest rate response to exchange rate movements, albeit with a small prior mean of 0.10 on this coefficient. The rule also allows for interest rate smoothing with a prior mean of 0.5. The confidence interval for the smoothing parameter ranges from 0.17 to 0.83.

The model is parameterized in terms of the steady state real interest rate r, rather than the discount factor β. r is annualized using the conversion $\beta = exp[-r/400]$. The common steady state inflation rate is set at a prior mean of 3 percent with a large standard deviation. The world-wide technology process, its mean growth rate and its autocorrelation coefficient specifically, is specified as in Lubik and Schorfheide (2005). They use United States and Euro-area data to estimate a reduced form system in output growth to fix priors. Since these two economic regions capture a substantial component of external factors affecting Australia and New Zealand, this appears a reasonably assumption. For the remainder of the prior specification I follow Lubik and Schorfheide (2005).

4 Benchmark estimation results

In my empirical analysis, I focus on three broad issues. First, I am interested in the magnitude of nominal rigidities, captured by the Calvo parameters. The rigidities in the import sectors, controlled by θ_{AU} and θ^*_{NZ}, determine the degree of exchange rate pass-through and play an important role in transmitting shocks across country borders. Secondly, I estimate monetary policy rules for Australia and New Zealand and study the propagation of monetary policy shocks. Unanticipated changes in monetary policy appear as innovations in the interest rate feedback rule, equation (33). The estimation of the policy coefficients, and hence the identification of the monetary policy shocks, is hindered by the joint endogeneity of the variables in the interest-rate feedback rule. Finally, I assess the relative importance of the various nominal and real structural shocks for explaining exchange rate movements.

4.1 Parameter estimates

The posterior means and 90 percent coverage regions of the benchmark specification are reported in Table 2. The estimates appear by and large reasonable, although a few results stand out. The estimates of the Calvo parameters tend to be on the high end, implying a substantial degree of rigidity in domestic and import prices in both economies. This stands in contrast with results reported in Justiniano and Preston (2004), whose estimates fall around 0.3, and Liu and Nicolaisen (2005), who report values of 0.7. Santacreu (2005), on the other hand, finds Calvo parameters in the 0.8 to 0.9 range. Note, however, that the data are informative on the Calvo parameters as there is a substantial shift and tightening of the posteriors relative to the priors. The results are unsatisfactory only insofar as they indicate that the Calvo parameters are not structural in a pure, theoretical sense. Instead, the estimation algorithm essentially chooses parameter values to match the volatility and persistence in the data. This involves trading off different exogenous and endogenous sources, such as habit persistence, technology, shocks and the intrinsic persistence implied by the Phillips-curve framework. The discrepancy in the results can thus be explained by model specification.

The posterior mean of the risk aversion parameter τ comes in at 1.96, the import share α at 0.30, and the habit parameter h at 0.32. The prior distributions are essentially not updated, indicating that the likelihood function is not informative with respect to these parameters. The estimated substitution elasticity between home and foreign goods, η, is 1.53, a number that is in line with the values typically used in calibration studies. This finding is reasonably robust to all specifications investigated. It suggests that home and foreign output are responsive to movements in terms of trade differentials, which in turn are related to the LOP gaps. Consequently, imperfect pass-through might play an important role in driving output. This issue is investigated further below using variance decompositions.

The results for the policy parameters are interesting as they point towards differential policy behaviour in the two central banks. The estimates for the RBNZ's policy rule reveal an inflation coefficient of 1.41, and output and exchange rate coefficients of 0.09 and 0.06, respectively. The RBA, on the other hand, shows less concern about inflation but responds to output growth with a coefficient of 0.75. The degree of interest rate smoothing is also substantially larger in Australia than in New Zealand (0.92 and 0.66, respectively). Again, there are differences with respect to other studies, the most striking being the findings in Lubik and Schorfheide (2003) who report inflation and output coefficients for New Zealand

(Australia) of 2.49 (2.10) and 0.26 (0.16), respectively.

I also included the depreciation rate as an argument in the policy rule. The estimated coefficients are small, even smaller than specified in the prior. This is consistent with results reported elsewhere (cf. Lubik and Schorfheide, 2003) and lends support to the idea that central banks do not respond consistently to exchange rate movements. However, two caveats apply. First, the small estimated coefficients do not mean that the exchange rate is not taken into account when setting monetary policy. The exchange rate does have an indirect influence on output movements via the terms of trade and on interest rate behaviour via CPI inflation. Moreover, there may be times when the Reserve Banks change their monetary stance in direct reaction to occurrences in foreign exchange markets. If these events are infrequent, it is highly unlikely they would be picked up by an estimation procedure using quarterly data that assesses 'average' monetary policy behaviour. Secondly, a formal assessment requires an overall test of relative model fit, a point that I examine further below.

The steady state real interest rate is estimated to be 2.83 percent, while the common inflation rate is 0.74 percent. The implied mean nominal interest rate is 3.6 percent. This is clearly the result of misspecification as the inflation series in both countries have different means. If, however, the model is to be taken seriously as a data generating process, then this long-run restriction has to be imposed in a two-country world. Finally, the estimated standard deviation of the PPP shock, σ_E, is large, suggesting that the model is unable to generate the real exchange rate fluctuations observed in the data. Since the importance of shocks cannot directly be assessed from the magnitude of the associated standard deviation due to normalization issues, I decompose the variance of exchange rate fluctuations in Section 4.3.

4.2 Impulse response analysis

I now study the dynamic behaviour of the two economies in response to exogenous shocks. The impulse response functions are depicted in Figure 1. Monetary policy shocks have the expected contractionary effects in both Australia and New Zealand: output and inflation decline, and the currency appreciates (a fall in the exchange rates). The responses in New Zealand are noticeably less persistent as the lagged interest rate coefficient in the RBNZ policy rule is significantly smaller than its Australian counterpart. A question of considerable interest is to what extent policy shocks are transmitted across countries. An increase in the New

Zealand interest rate leads to an increase in Australia's output, as well as its inflation and interest rate. Transmission, however, is asymmetric as Australian policy shocks contract New Zealand's output. There are two mechanisms at play that can explain this result. The first is related to the risk-sharing mechanism. As output contracts resources are shifted to the location where they can be most productive. This is captured by the terms of trade improvement associated with the appreciation of the NZ dollar. At the same time, the monetary policy channel is in effect. The strong RBNZ interest rate response to Australian contractions acts as a damper on the favorable exchange rate movement thereby contracting output.[8]

The effect of country-specific technology shocks is also asymmetric. Shocks arising in New Zealand lead to an increase in domestic output and a fall in inflation. In Australia, however, idiosyncratic productivity shocks are contractionary as postulated in Gali (2004) as a typical facet of New Keynesian-type models. Interestingly, technology shocks tend to appreciate the currency, although the effect is much more precisely estimated in Australia than in New Zealand. Foreign expenditure shocks follow a similar pattern as technology shocks as they lead to domestic expansions, declines in prices on account of a crowding out effect and a contractionary monetary policy response. Moreover, the currency appreciates. Cross-country transmission is similarly positive from New Zealand to Australia, but negative in the opposite direction.

Finally, world technology shocks are across the board expansionary, accompanied by an, albeit insignificant, depreciation of the New Zealand dollar. This again is due to the stronger interest rate response overall in Australia. As an aside, shocks to the PPP error by definition lead to an increase in the exchange rate. By virtue of the monetary policy rule containing an interest rate term, other endogenous variables move as well. This illustrates a danger of specifically responding to exchange rate movements as it may introduce undesirable fluctuations in aggregate variables above and beyond the exchange rate component of the CPI. This is a point highlighted and further discussed in Lubik and Schorfheide (2003).

4.3 Variance Decompositions

While impulse response analysis can give some insight into the inner workings of the model, it can not conclusively answer which channels are quantitatively

[8] This specific response is, however, highly model dependent. Lubik and Schorfheide (2005) show that for the US and the Euro-area monetary policy transmission is fairly symmetric.

important. However, the estimation methodology allows one to decompose exchange rate volatility into individual components explained by the disturbances in the model. The model is driven by seven structural shocks (monetary policy, technology, and foreign expenditure) to which I added an additional disturbance in the form of an error term appended to the equation defining the nominal (exchange rate) depreciation rate. The disturbance is not strictly structural since it is not contained in the model's primitives.

The exchange rate shock captures deviations from PPP not already explained endogenously through imperfect pass-through. This procedure differs from adding errors to the measurement equation, which are more akin to actual measurement errors; it also differs from Bergin (2004), who adds shocks to the UIP and PPP equations, but allows them to be correlated with each other and other shocks in the model. Bergin shows that different orthogonalization schemes change the variance decompositions considerably. He reports that monetary policy shocks contribute between 50 and 70 percent to exchange rate movements at longer horizons. It is therefore not a priori clear whether the influence attributed to monetary policy shocks is the artefact of an orthogonalization scheme.

Nevertheless, it is often instructive to add idiosyncratic disturbances as they provide a measure of the extent to which the data are explained by specific features of the model. In a purely econometric sense, introducing these shocks allows a better fit of individual equations since they do not appear anywhere else in the model and do not have to obey any cross-equation restrictions. Without these shocks, the estimation procedure attempts to fit the model's unobservables based on tightly restricted equations, which may sometimes result in implausible parameter estimates.

I report variance decompositions for the model's observables in Table 3. The main driving forces of output in Australia and New Zealand are foreign expenditure shocks (34 percent and 72 percent, respectively) and worldwide technology shocks (33 percent and 23 percent, respectively). Domestic sources do not play a significant role, except for monetary policy shocks in Australia which explain 18 percent of output movements. The importance of Australian monetary policy is likely to be associated with the large estimated output coefficient, since interest rate shocks feed back to output contemporaneously. Home-grown technology shocks do matter for the determination of inflation: they account for 77 percent of the variation in inflation in New Zealand, and 91 percent in Australia. They also have similar effects on interest rate movements in both countries with 30 percent and 65 percent, respectively.

Interestingly, there is virtually no cross-country influence from country-specific shocks. The largest contribution is from Australian technology shocks on New Zealand inflation of less than 10 percent. Monetary policy shocks are not transmitted at all. This likely reflects the lack of fit of the UIP relation, which provides the only direct link between the two interest rate processes. I investigated the plausibility of this finding further by allowing for correlation in the monetary policy shocks.[9] As a prior for the cross-correlation coefficient I imposed a uniform distribution on the interval $[-1,1]$. The posterior estimates of the structural parameters are virtually identical to the benchmark specification. The estimated correlated coefficient was 0.03 with the same coverage as the prior distribution. This finding supports the conclusion that monetary policy between the Antipodean central banks is not coordinated.

Finally, I assess the driving forces behind exchange rate movements. In the benchmark estimation, PPP-shocks explain 85 percent of the variability of the depreciation rate. This result had already been hinted at by the estimated variance of the PPP-shock, which is an order of magnitude larger than those of the other disturbances. The second largest components are the monetary policy shocks, followed by the Australian technology shocks. By and large, the contribution of the other shocks is negligible. I will discuss the reasons and implications of these findings in the robustness section.

5 Assessing robustness

Estimation of the benchmark model has established a few interesting conclusions. First, there are notable differences in the estimated structural parameters, in particular the policy parameters. Second, the model implies that the responses to country-specific shocks and the transmission of monetary policy shocks are asymmetric. However, these discrepancies and asymmetries are quantitatively insignificant as aggregate variables are driven largely by own-country specific disturbances. Moreover, only about 15 percent of the variation in the bilateral exchange rate can be explained by endogenous factors.

I now study the robustness of these findings by estimation variants of the benchmark model. I begin by concentrating on the monetary policy rule, while leaving the specification of the rest of the model unchanged. Specifically, I re-estimate the model conditional on whether there is or is not an exchange rate variable in the

[9] These results are not reported, but are available from the author upon request.

policy rule. Secondly, I take a closer look at the sources of exchange rate fluctuations based on variance decompositions for different monetary policy and shock specifications. Third, I relax the specification of the prior for the other structural parameters.

5.1 Do central banks respond to exchange rate movements?

This section revisits a question posed by Lubik and Schorfheide (2003) in a small open economy Bayesian DSGE framework. They found that the Reserve Banks of Australia and New Zealand did not consistently respond to exchange rate movements in the last two decades. This result was particularly pronounced in the case of Australia, which emerged as a strict and aggressive inflation targeter. Even during New Zealand's MCI episode, the RBNZ did not appear to take exchange rate movements into account in setting policy. Lubik and Schorfheide's findings were robust over a range of specifications for the monetary policy rule. What distinguishes the present paper from this earlier work is the two-country setting as well as differences in the way the data are treated, specifically the detrending procedure. That these differences can affect the estimates is already apparent from the discussion above: the policy coefficient are estimated to be considerably smaller, and Australia is found to respond strongly to output growth.

Testing the specification of the policy rule involves re-estimating the model and computing the marginal data densities, ie the value of the posterior with parameters integrated out. A comparison of two model specifications then involves comparing the two values. Under the assumption of a flat prior – or indifference between the two models – this is a straightforward way of assessing relative fit.

I conduct three experiments. First, I re-estimate the model setting the exchange rate coefficients in both countries' policy rules to zero. Second, I turn off the RBNZ's policy response to the exchange rate, leaving the RBA's unrestricted. And then third, I restrict the RBA's policy response, but leave the RBNZ's response unrestricted. The posterior estimates are reported in Table 2.

The picture that emerges from the fully restricted estimation is that the Calvo parameters are all smaller than the benchmark estimates, while the preference parameters are unchanged, with the exception of the intratemporal substitution elasticity which drops from 1.53 to 1.24. Turning off the policy response to the exchange rate results in New Zealand policy responding more strongly to inflation, while the Australian policy coefficients are largely unaffected. The restricted estimation trades off more persistence in the inflation process against a more aggressive policy stance. The marginal data densities (MDD) do paint a clear picture, however. The value for the benchmark model is -407.4 against a value of -402.2 for the restricted model. This is clear-cut acceptance of the hypothesis that neither central bank responds to exchange rate movements, thus confirming the findings in Lubik and Schorfheide (2003).[10]

In the next step, I restrict the New Zealand exchange rate coefficient to zero. The estimates take on values that lie between the two extremes discussed above. In particular, high Calvo parameters tend to be associated with less aggressive monetary policy, but there is too much overlap in the 90 percent coverage regions to draw definitive conclusions. The MDD for this specification is -404.3. This implies the restricted model is preferred to the benchmark specification, but it is rejected against the hypothesis that there is no direct policy response to the exchange rate.

Finally, I restrict the Australian exchange rate coefficient to zero. The (preliminary) results were highly unsatisfactory as the estimation algorithm had convergence problems. The Calvo parameters in Australia were running towards one, while the inflation coefficient in the New Zealand rule was returned at 0.76 which is at the boundary of the indeterminacy region. The MDD was -440.0 which clearly rejects this specification.

The conclusion emerging from this section is that a monetary policy rule specification without an explicit exchange rate response is most consistent with the behaviour of the aggregate time series in the Antipodes during the sample period. The robustness of this result needs to be evaluated further by allowing for further variations in the monetary policy rules, such as allowing for expected inflation targeting or a response to international relative prices.

5.2 What determines Antipodean exchange rate fluctuations?

I now take another look at the determination of bilateral exchange rates. The benchmark estimation has shown that the benchmark model can explain 15 percent of the observed exchange rate volatility. Compared to the results found in the literature, this estimate is at the high end. Various decompositions for alternative

[10] Note the marginal data density contains a penalty for overparameterization similar to the Bayesian Information Criterion (BIC), which can twist the results in a specific direction. The difference between the MDDs is, however, large enough that this is not a big concern.

model specifications can be found in Table 5. Note that the prior distributions also induce priors for the forecast error decompositions.

It turns out that the data are very informative with respect to the variance decompositions. Under the prior the PPP-shock explains about 64 percent of exchange rate fluctuations, while foreign expenditure shocks make the biggest model-based contribution. In the benchmark estimation, PPP-shocks explain 85 percent of the variability of the depreciation rate. This result had already been hinted at by the estimated variance of the PPP-shock, reported in Table 2, which is an order of magnitude larger than those of other disturbances. The second largest component arises from the monetary policy shocks. By and large, the contribution of real shocks is minor, the exception being Australian technology shocks with 4 percent. As far as the other specifications are concerned, the results change only insignificantly; Australian technology shocks become slightly more important.

These findings are not immediately comparable to other contributions in the literature mainly because different methodologies are applied. Calibration studies typically only study one shock at a time and attempt to match a small set of statistics with large degrees of freedom in setting parameters. Using long-run identification restrictions in a VAR framework Ahmed, Ickes, Wang, and Yoo (1993) do not find support for a role of monetary policy shocks in exchange rate dynamics. On the other hand, in a VAR study using similar identification, Clarida and Gali (1994) show that monetary shocks, demand shocks in their interpretation, are a main driving force behind output movements over short horizons. This suggests that the lack of explanatory power derives from the disconnect between output movements and relative prices that is also evident in the model.[11]

Overall, these results do not lend support to the notion that exchange rate dynamics are largely driven by real shocks, at least as far the endogenous components are concerned. The benchmark model can explain roughly 15 percent of the movements in the depreciation rate, but further robustness checks have to be performed.

5.3 Relaxing the priors

I now assess the extent to which a relaxation of the priors affects the outcomes of the estimation. Posterior estimates are reported in Table 7. I first investigate whether the imperfect pass-through channel matters for exchange rate de-

[11] This exchange rate disconnect puzzle has been emphasized by Rogoff (1996) as the main challenge for open economy macro models.

termination. Consequently the Calvo-parameters θ_F and θ_F^* are set equal to zero, while the other priors are unchanged from the benchmark without exchange rate response.[12] The estimates of the domestic stickiness parameters are virtually unchanged, as are the intertemporal substitution elasticity τ and the habit persistence parameter h. The coefficients of the policy rules also reflect the benchmark estimates. What did change, however, are the estimates of the preference parameters in the consumption aggregator. The intratemporal substitution elasticity dropped slightly from 1.24 to 1.05, while the import share α declined from 0.29 to 0.11 – and this despite a tight prior distribution centreed on a value of 0.3.

This result is somewhat puzzling since it appears to suggest that the data are very informative with respect to the import share in the perfect pass-through specification, but not under imperfect pass-through where the estimates essentially replicated the prior.

That the specification of pass-through can have an effect is apparent from equation (28). The estimation algorithm 'adapts' α to match the model-implied volatility of the real exchange rate and the terms of trade, which differs depending on whether $\widetilde{\psi}_t$ is zero or not. But note also that the import share appears in conjunction with η in the risk-sharing condition (32), which determines how terms of trade movements affect output growth. Consequently, estimates depend on how the prior assigns weights to individual components of the reduced-form coefficient. This observation is an example of the identification issue highlighted by Lubik and Schorfheide (2005). There is a clear tension between extraneous information, ie the actually observed trade share in the data, and the requirements of the estimation algorithm to fit aggregate data. Moreover, this raises the issue of whether this structural estimation approach actually recovers 'structural' parameters. In a somewhat more positive light, this may just be evidence of simple misspecification-induced bias.

The marginal data density of this specification is -423.3, which leads me to reject the perfect pass-through specification in favor of the benchmark. It thus seems that deviations from PPP do matter for exchange rate determination. This is also borne out by the results from the variance decomposition. 92 percent of observed exchange rate movements are explained by the measurement error in the PPP equation. Movements in the law of one price gap thus clearly provide the added endogenous explanatory power.

[12] I have tested whether the exchange rate should be included in the monetary policy rules and came to the same conclusion derived before. In the following robustness checks, I thus refer to this as the benchmark specification.

In the next robustness check, I relax the priors on the Calvo parameters and on the AR(1)-coefficients in the exogenous process by imposing uniform distributions. Overall, this specification is also rejected compared to the benchmark with an MDD of -456.1. The estimates of the Calvo parameters all run towards 1, which implies almost perfect price stickiness. This is compensated for by very persistent estimates of the auto-regressive parameters. The pattern of the policy rule parameters is maintained, although inflation coefficients are lower than in the benchmark, while output coefficients are higher. Interestingly, the model now does a better job in explaining exchange rate movements than the benchmark, but this is likely due to the high implied import price stickiness.

6 Conclusion

This paper has analyzed the sources of business cycle fluctuations and the transmission mechanism in Australia and New Zealand. A few robust conclusions have emerged. First, neither the RBNZ nor the RBA consistently respond to exchange rate movements. This finding confirms earlier research based on structural estimation for the two countries. Secondly, the main source of business cycles in the Antipodes is foreign, that is rest of the world expenditure shocks as well as world wide technology shocks. Thirdly, the model does a respectable job in explaining exchange rate movements in that roughly 15 percent can be traced to sources endogenous to the model. Finally, the transmission of business cycles between the two countries is asymmetric, but quantitatively insignificant.

The paper has utilized a structural estimation approach using Bayesian methods. The cross-equation restrictions embedded in the underlying model's first order conditions provide restrictions that allow identification of the structural parameters. Even if identification is not possible in a classical econometric sense, it may be achieved by utilizing extraneous information through the use of priors. However, robustness checks show that marginally altering the model specification or imposing less informative priors is problematic, since parameter estimates often change substantially. This is likely due to misspecification that imposes potentially invalid cross-equation restrictions. It is virtually impossible to trace out the sources of the misspecification problem, due to the highly non-linear nature of the structural estimation procedure. Some insight may be gained, however, by further assessing the robustness of the conclusions to alternative model specifications.

The benchmark model makes a few assumptions that presumably are critical for the findings. Essentially, I assume a two-country world that is driven by unspecified rest-of-the-world shocks. By virtue of the perfect risk-sharing assumptions, the two economies could be thought of as a unified economic area, and are then conceptually a closed economy. The model specification thus loses some of its open economy flavour. This can be remedied by: (i) imposing imperfect risk-sharing, which would also allow the analysis of current account movements; (ii) explicitly modelling the rest of the world, for instance as a 3-equation closed-economy New Keynesian world;[13] and (iii) by treating the Antipodes as two small open economies with a fully specified foreign economy. Worthwhile extensions include introducing a non-traded sector, investment and capital acuumulation, and an explicit labour market to analyze employment fluctuations. However, any of these modifications would increase the complexity (and the numerical burden) significantly.

References

Ahmed, S, B Ickes, P Wang, and B S Yoo (1993), "International business cycles," *American Economic Review*, 83, 335–359.

Bergin, P R (2004), "How well can the new open economy macroeconomics explain the exchange rate and the current account?" *Journal of International Money and Finance*, forthcoming.

Buckle, R A, K Kim, H Kirkham, N McLellan, and J Sharma (2002), "A structural VAR model of the New Zealand business cycle," *New Zealand Treasury Working Paper*, 02/26.

Chari, V V, P Kehoe, and E McGrattan (2002), "Can sticky price models generate volatile and persistent real exchange rates?" *Review of Economic Studies*, 69, 533–563.

Clarida, R and J Galí (1994), "Sources of real exchange rate fluctuations," *Carnegie-Rochester Conference Series on Public Policy*, 41, 1–56.

Dungey, M and A Pagan (2000), "A structural VAR model of the Australian economy," *The Economic Record*, 76, 321–342.

[13] Justiniano and Preston (2004) report some results along these lines. They point out, however, that the joint estimation of a small open economy model and a closed econmy rest-of-the-world specification did not improve their model's fit.

Galí, J and T Monacelli (2005), "Monetary policy and exchange rate volatility in a small open economy," *Review of Economic Studies*, forthcoming.

Geweke, J (1999), "Using simulation methods for Bayesian econometric models: Inference, development, and communication," *Econometric Reviews*, 18, 1–126.

Jeffreys, H (1961), *Theory of Probability*, Oxford University Press, Oxford.

Justiniano, A and B Preston (2004), "Small open economy DSGE models: Specification, estimation and model fit," *Manuscript*, IMF and Columbia University.

Liu, P (2005), "A small new Keynesian model of the New Zealand economy," *Reserve Bank of New Zealand Discussion Paper*, forthcoming.

Lubik, T A (2005), "Monetary policy and incomplete pass-through: A tale of two countries," *Mimeo*, Department of Economics, The Johns Hopkins University.

Lubik, T A and F Schorfheide (2003), "Do central banks respond to exchange rate movements? A structural investigation," *The Johns Hopkins University, Department of Economics Working Paper*, 505.

Lubik, T A and F Schorfheide (2005), "A Bayesian look at new open economy macroeconomics," *NBER Macroeconomics Annual*, forthcoming.

Lubik, T A and W Teo (2005), "Do world shocks drive domestic business cycles? some evidence from structural estimation," *The Johns Hopkins University, Department of Economics Working Paper*, 522.

Monacelli, T (2005), "Monetary policy in a low pass-through environment," *Journal of Money, Credit, and Banking*, forthcoming.

Rogoff, K (1996), "The purchasing power parity puzzle," *Journal of Economic Literature*, 34, 647–68.

Santacreu, A M (2005), "Bayesian analysis of monetary policy in a multisectoral small open economy: The case of New Zealand," *Reserve Bank of New Zealand Discussion Paper*, forthcoming.

Schwarz, G (1978), "Estimating the dimension of a model," *Annals of Statistics*, 6, 461–4.

Sims, C A (2002), "Solving linear rational expectations models," *Computational Economics*, 20, 1–20.

Table 1
PRIOR DISTRIBUTION (BENCHMARK), PART 1

Name	Domain	Density	Para (1)	Para (2)
θ_H	$[0,1)$	Beta	0.50	0.15
θ_F	$[0,1)$	Beta	0.50	0.15
θ_H^*	$[0,1)$	Beta	0.50	0.15
θ_F^*	$[0,1)$	Beta	0.50	0.15
τ	$\boldsymbol{R}^+$	Gamma	2.00	0.50
h	$[0,1)$	Beta	0.30	0.10
α	$[0,1)$	Beta	0.30	0.05
η	$\boldsymbol{R}^+$	Gamma	1.00	0.50
ψ_1	$\boldsymbol{R}^+$	Gamma	1.50	0.25
ψ_2	$\boldsymbol{R}^+$	Gamma	0.50	0.25
ψ_3	$\boldsymbol{R}^+$	Gamma	0.10	0.05
ψ_1^*	$\boldsymbol{R}^+$	Gamma	1.50	0.25
ψ_2^*	$\boldsymbol{R}^+$	Gamma	0.50	0.25
ψ_3^*	$\boldsymbol{R}^+$	Gamma	0.10	0.05
ρ_A	$[0,1)$	Beta	0.80	0.10
ρ_R	$[0,1)$	Beta	0.50	0.20
ρ_{EXP}	$[0,1)$	Beta	0.80	0.10
ρ_A^*	$[0,1)$	Beta	0.60	0.20
ρ_R^*	$[0,1)$	Beta	0.50	0.20
ρ_{EXP}^*	$[0,1)$	Beta	0.80	0.10
ρ_Z	$[0,1)$	Beta	0.66	0.15

Notes: Para (1) and Para (2) list the means and the standard deviations for Beta, Gamma, and Normal distributions; the upper and lower bound of the support for the Uniform distribution; s and ν for the Inverse Gamma distribution, where $p_{\mathscr{IG}}(\sigma|\nu,s) \propto \sigma^{-\nu-1}e^{-\nu s^2/2\sigma^2}$. The effective prior is truncated at the boundary of the determinacy region.

Table 1
PRIOR DISTRIBUTION (BENCHMARK), PART 2

Name	Domain	Density	Para (1)	Para (2)
$r^{(A)}$	$\boldsymbol{R}^+$	Gamma	0.50	0.50
γ	$\boldsymbol{R}$	Normal	0.40	0.20
$\pi^{(A)}$	$\boldsymbol{R}^+$	Gamma	7.00	2.00
σ_A	$\boldsymbol{R}^+$	InvGamma	1.00	4.00
σ_G	$\boldsymbol{R}^+$	InvGamma	1.00	4.00
σ_R	$\boldsymbol{R}^+$	InvGamma	0.40	4.00
σ_{A^*}	$\boldsymbol{R}^+$	InvGamma	0.40	4.00
σ_{EXP^*}	$\boldsymbol{R}^+$	InvGamma	1.00	4.00
σ_{R^*}	$\boldsymbol{R}^+$	InvGamma	0.20	4.00
σ_Z	$\boldsymbol{R}^+$	InvGamma	0.50	4.00
σ_E	$\boldsymbol{R}^+$	InvGamma	3.50	4.00

Notes: The prior is truncated at the boundary of the determinacy region. Para (1) and Para (2) list the means and the standard deviations for Beta, Gamma, and Normal distributions; the upper and lower bound of the support for the Uniform distribution; s and ν for the Inverse Gamma distribution, where $p_{\mathcal{IG}}(\sigma|\nu,s) \propto \sigma^{-\nu-1}e^{-\nu s^2/2\sigma^2}$.

Table 2
POSTERIOR ESTIMATES

	Benchmark		Spec. (I)		Spec. (II)	
Parameter	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval
θ_H	0.90	[0.84, 0.95]	0.84	[0.76, 0.92]	0.89	[0.83, 0.94]
θ_F	0.82	[0.72, 0.94]	0.76	[0.64, 0.89]	0.79	[0.67, 0.93]
θ_H^*	0.87	[0.76, 0.98]	0.83	[0.72, 0.96]	0.83	[0.72, 0.95]
θ_F^*	0.93	[0.88, 0.96]	0.91	[0.88, 0.95]	0.93	[0.90, 0.96]
τ	1.96	[1.24, 2.59]	1.97	[1.24, 2.60]	1.95	[1.32, 2.63]
h	0.32	[0.14, 0.51]	0.35	[0.13, 0.56]	0.32	[0.13, 0.50]
α	0.30	[0.21, 0.39]	0.29	[0.21, 0.37]	0.27	[0.19, 0.34]
η	1.53	[0.55, 2.61]	1.24	[0.42, 2.03]	1.37	[0.50, 2.23]
ψ_1	1.41	[0.99, 1.76]	1.67	[1.08, 2.23]	1.51	[1.00, 2.05]
ψ_2	0.10	[0.02, 0.16]	0.04	[0.01, 0.08]	0.09	[0.01, 0.16]
ψ_3	0.06	[0.02, 0.10]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ψ_1^*	1.30	[0.92, 1.67]	1.30	[0.94, 1.66]	1.30	[0.96, 1.64]
ψ_2^*	0.74	[0.26, 1.19]	0.68	[0.29, 1.08]	0.75	[0.31, 1.19]
ψ_3^*	0.09	[0.03, 0.15]	0.00	[0.00, 0.00]	0.09	[0.03, 0.17]
ρ_A	0.85	[0.76, 0.96]	0.73	[0.59, 0.89]	0.80	[0.62, 0.96]
ρ_R	0.66	[0.56, 0.77]	0.60	[0.50, 0.71]	0.64	[0.55, 0.75]
ρ_{EXP}	0.82	[0.74, 0.91]	0.87	[0.81, 0.94]	0.83	[0.74, 0.92]
ρ_A^*	0.97	[0.95, 0.99]	0.98	[0.96, 1.00]	0.97	[0.97, 0.99]
ρ_R^*	0.93	[0.88, 0.97]	0.92	[0.89, 0.96]	0.93	[0.90, 0.97]
ρ_{EXP}^*	0.75	[0.64, 0.88]	0.72	[0.60, 0.86]	0.75	[0.60, 0.88]
ρ_Z	0.63	[0.37, 0.92]	0.55	[0.31, 0.80]	0.57	[0.32, 0.83]
$r^{(A)}$	2.84	[1.99, 3.73]	3.01	[2.27, 3.74]	2.78	[2.12, 3.49]
γ	0.63	[0.43, 0.80]	0.65	[0.49, 0.81]	0.65	[0.50, 0.82]
$\pi^{(A)}$	0.74	[0.19, 1.29]	0.61	[0.29, 0.96]	0.69	[0.30, 1.11]
σ_A	2.12	[0.77, 3.93]	1.86	[0.74, 3.22]	2.01	[0.86, 3.67]
σ_{EXP}	0.96	[0.73, 1.21]	0.89	[0.69, 1.07]	0.96	[0.72, 1.21]
σ_R	0.23	[0.20, 0.28]	0.23	[0.19, 0.28]	0.23	[0.18, 0.28]
σ_{A^*}	0.89	[0.27, 1.52]	0.48	[0.27, 0.73]	0.78	[0.26, 1.46]
σ_{EXP^*}	0.66	[0.47, 0.83]	0.62	[0.47, 0.76]	0.65	[0.47, 0.81]
σ_{R^*}	0.12	[0.09, 0.14]	0.12	[0.09, 0.14]	0.12	[0.10, 0.14]
σ_Z	0.32	[0.23, 0.42]	0.35	[0.23, 0.49]	0.34	[0.23, 0.44]
σ_E	2.78	[2.27, 3.24]	2.83	[2.38, 3.29]	2.76	[2.33, 3.20]

Notes: The table reports posterior means and 90 percent probability intervals (in brackets). The posterior summary statistics are calculated from the output of the posterior simulator. Spec. (I) refers to the model with no exchange rate response in both countries, Spec. (II) to exchange rate response in Australia only.

Table 3
VARIANCE DECOMPOSITIONS

	Output	Inflation	Interest	Output*	Inflation*	Interest*	Exch. Rate
Mon. Policy	0.02	0.03	0.50	0.05	0.00	0.01	0.04
	[0.00, 0.04]	[0.00, 0.07]	[0.19, 0.74]	[0.01, 0.09]	[0.00, 0.00]	[0.00, 0.01]	[0.02, 0.06]
Mon. Policy*	0.00	0.01	0.00	0.18	0.00	0.15	0.03
	[0.00, 0.01]	[0.00, 0.02]	[0.00, 0.01]	[0.06, 0.29]	[0.00, 0.02]	[0.02, 0.28]	[0.01, 0.05]
Technology	0.01	0.77	0.30	0.00	0.02	0.01	0.01
	[0.00, 0.03]	[0.46, 0.99]	[0.06, 0.52]	[0.00, 0.01]	[0.00, 0.08]	[0.00, 0.02]	[0.00, 0.02]
Technology*	0.00	0.09	0.03	0.06	0.91	0.66	0.04
	[0.00, 0.01]	[0.00, 0.02]	[0.00, 0.10]	[0.00, 0.11]	[0.67, 0.99]	[0.20, 0.97]	[0.00, 0.07]
For. Exp.	0.72	0.04	0.03	0.01	0.00	0.00	0.01
	[0.52, 0.91]	[0.00, 0.09]	[0.00, 0.07]	[0.00, 0.01]	[0.00, 0.00]	[0.00, 0.00]	[0.00, 0.02]
For. Exp.*	0.00	0.01	0.00	0.34	0.01	0.03	0.01
	[0.00, 0.01]	[0.00, 0.02]	[0.00, 0.01]	[0.12, 0.55]	[0.00, 0.03]	[0.00, 0.06]	[0.00, 0.03]
World Tech.	0.23	0.05	0.10	0.33	0.04	0.14	0.00
	[0.05, 0.45]	[0.00, 0.18]	[0.00, 0.31]	[0.11, 0.64]	[0.00, 0.15]	[0.00, 0.55]	[0.00, 0.01]
PPP Shock	0.00	0.00	0.02	0.01	0.00	0.00	0.85
	[0.00, 0.00]	[0.00, 0.01]	[0.00, 0.05]	[0.00, 0.02]	[0.00, 0.00]	[0.00, 0.01]	[0.77, 0.92]

Notes: The table reports posterior means and 90 percent probability intervals (in brackets). The posterior summary statistics are calculated from the output of the posterior simulator. The asterisks in the first column and first row denote Australian-specific shocks and variables.

Table 4
LOG MARGINAL DATA DENSITIES

Benchmark Prior	ψ_3^{NZ}, ψ_3^{AU} estimated	-407.4
Benchmark Prior	$\psi_3^{NZ} = \psi_3^{AU} = 0$	-402.2
Benchmark Prior	$\psi_3^{NZ} = 0, \psi_3^{AU}$ estimated	-404.3
Benchmark Prior	ψ_3^{NZ} estimated, $\psi_3^{AU} = 0$	-440.0
Perfect Pass-through	$\psi_3^{NZ} = \psi_3^{AU} = 0$	-423.3
Diffuse Prior	$\psi_3^{NZ} = \psi_3^{AU} = 0$	-456.5

Notes: The log marginal data densities for the DSGE model specifications are computed based on Geweke's (1999) modified harmonic mean estimator.

Table 5
VARIANCE DECOMPOSITIONS OF DEPRECIATION RATE

	Prior Benchmark		Posterior Benchmark		$\psi_3^{NZ} = 0$, $\psi_3^{AU} = 0$		$\psi_3^{NZ} = 0$, ψ_3^{AU} estimated	
	Mean	90% Int.	Mean	90% Int.	Mean	90% Int.	Mean	90% Int.
Mon. Policy	0.04	[0.00, 0.10]	0.04	[0.02, 0.06]	0.03	[0.01, 0.05]	0.03	[0.01, 0.05]
Mon. Policy*	0.01	[0.00, 0.02]	0.03	[0.01, 0.05]	0.03	[0.01, 0.04]	0.03	[0.01, 0.05]
Stat. Tech.	0.08	[0.00, 0.23]	0.01	[0.00, 0.02]	0.00	[0.00, 0.01]	0.01	[0.00, 0.01]
Stat. Tech.*	0.01	[0.00, 0.01]	0.04	[0.00, 0.07]	0.04	[0.01, 0.07]	0.06	[0.01, 0.10]
For. Exp.	0.09	[0.00, 0.24]	0.01	[0.00, 0.02]	0.00	[0.00, 0.00]	0.01	[0.00, 0.02]
For. Exp.*	0.10	[0.00, 0.28]	0.01	[0.00, 0.03]	0.01	[0.00, 0.02]	0.01	[0.00, 0.02]
World Tech.	0.01	[0.00, 0.02]	0.00	[0.00, 0.01]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
PPP Shock	0.64	[0.27, 0.98]	0.85	[0.77, 0.92]	0.88	[0.83, 0.94]	0.85	[0.78, 0.94]

Notes: The table reports prior and posterior means and 90 percent probability intervals (in brackets). The posterior summary statistics are calculated from the output of the posterior simulator.

Table 6
ALTERNATIVE PRIOR DISTRIBUTIONS

Name	Domain	Density	Para (1)	Para (2)
Perfect Pass-through				
θ_F	$[0,1)$	Fixed	0.00	
θ_H^*	$[0,1)$	Fixed	0.00	
Diffuse Prior				
θ_H	$[0,1)$	Uniform	0.00	1.00
θ_F	$[0,1)$	Uniform	0.00	1.00
θ_H^*	$[0,1)$	Uniform	0.00	1.00
θ_F^*	$[0,1)$	Uniform	0.00	1.00
ρ_A	$[0,1)$	Uniform	0.00	1.00
ρ_R	$[0,1)$	Uniform	0.00	1.00
ρ_{EXP}	$[0,1)$	Uniform	0.00	1.00
ρ_A^*	$[0,1)$	Uniform	0.00	1.00
ρ_R^*	$[0,1)$	Uniform	0.00	1.00
ρ_{EXP}^*	$[0,1)$	Uniform	0.00	1.00

Notes: Para (1) and Para (2) list the means and the standard deviations for Beta, Gamma, and Normal distributions; the upper and lower bound of the support for the Uniform distribution.

Table 7
POSTERIOR ESTIMATES UNDER ALTERNATIVE PRIORS

	Benchmark		Perfect Pass-through		Diffuse Prior	
	Mean	90% Interval	Mean	90% Interval	Mean	90% Interval
θ_H	0.84	[0.76, 0.92]	0.83	[0.72, 0.92]	0.98	[0.94, 1.00]
θ_F	0.76	[0.64, 0.89]	0.00	[0.00, 0.00]	0.99	[0.93, 1.00]
θ_H^*	0.83	[0.72, 0.96]	0.00	[0.00, 0.00]	0.95	[0.88, 0.99]
θ_F^*	0.91	[0.88, 0.95]	0.90	[0.86, 0.94]	0.96	[0.89, 1.00]
τ	1.97	[1.24, 2.60]	1.89	[1.28, 2.53]	2.35	[1.45, 3.10]
h	0.35	[0.13, 0.56]	0.40	[0.20, 0.59]	0.28	[0.11, 0.45]
α	0.29	[0.21, 0.37]	0.11	[0.07, 0.15]	0.10	[0.01, 0.18]
η	1.24	[0.42, 2.03]	1.05	[0.32, 1.72]	0.75	[0.45, 0.97]
ψ_1	1.67	[1.08, 2.23]	1.75	[1.10, 2.40]	1.02	[0.66, 1.78]
ψ_2	0.04	[0.01, 0.08]	0.04	[0.00, 0.07]	0.10	[0.04, 0.16]
ψ_3	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
ψ_1^*	1.30	[0.94, 1.66]	1.25	[0.88, 1.59]	1.24	[0.85, 1.61]
ψ_2^*	0.68	[0.29, 1.08]	0.74	[0.30, 1.09]	0.98	[0.42, 1.24]
ψ_3^*	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]

Notes: The table reports posterior means and 90 percent probability intervals (in brackets), calculated from the output of the posterior simulator. $\psi_3 = \psi_3^* = 0$ in all specifications.

Table 8
VARIANCE DECOMPOSITIONS OF THE DEPRECIATION RATE

	Benchmark, $\psi_3 = \psi_3^* = 0$		Perfect Pass-through		Diffuse Prior	
	Mean	90% Int.	Mean	90% Int.	Mean	90% Int.
Monetary Policy	0.03	[0.01, 0.05]	0.02	[0.01, 0.02]	0.00	[0.00, 0.00]
Monetary Policy*	0.03	[0.01, 0.04]	0.02	[0.02, 0.03]	0.00	[0.00, 0.00]
Stat Technology	0.00	[0.00, 0.01]	0.01	[0.00, 0.01]	0.07	[0.00, 0.14]
Stat Technology*	0.04	[0.01, 0.07]	0.02	[0.00, 0.04]	0.06	[0.00, 0.11]
For. Exp.	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.04]
For. Exp.*	0.01	[0.00, 0.02]	0.01	[0.00, 0.01]	0.00	[0.00, 0.00]
World Technology	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]	0.00	[0.00, 0.00]
PPP Shock	0.88	[0.83, 0.94]	0.92	[0.89, 0.96]	0.85	[0.73, 1.00]

Notes: The table reports prior and posterior means and 90 percent probability intervals (in brackets). The posterior summary statistics are calculated from the output of the posterior simulator.

Figure 1
Impulse responses