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# Transmitting shocks to the economy: The contribution of interest and exchange rates and the credit channel

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# Transmitting shocks to the economy: The contribution of interest and exchange rates and the credit channel *

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**Abstract**

Understanding the transmission channels of shocks is critical for successful policy response. This paper develops a dynamic general equilibrium model to assess the relative importance of the interest rate, the exchange rate and the credit channels in transmitting shocks in an open economy. The relative contribution of each channel is determined by comparing the impulse responses when the relevant channel is suppressed with the impulse responses when all three channels are operating. The results suggest that all three channels contribute to business cycle fluctuations and the transmission of shocks to the economy. But the magnitude of the impact of the interest rate channel crucially depends on the inflation process and the structure of the economy.

JEL classification: E32, E44, E50, F41

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# 1 Introduction

This paper develops a dynamic general equilibrium model to assess the relative importance of the interest rate, the exchange rate and the credit channels in transmitting shocks in an open economy. Incomplete or erroneous understanding of the transmission mechanisms may cause delayed or inappropriate policy responses that can have harmful and long lasting effects on the economy. To conduct policy timely and successfully requires an understanding of the channels through which shocks affect the decisions of firms, households and financial intermediaries that in turn alter the level of economic activity and inflation.

Much of the literature to date has tended to focus on the interest rate, the exchange rate and the credit channels separately.[1] The contribution of this paper is to incorporate all three channels in a single model and to analyse their relative importance in transmitting shocks to the economy.

The framework of analysis is a small open economy that operates under a flexible exchange with imperfect competition and sticky prices. The model is calibrated for New Zealand. The choice of calibration was led by the structure of the New Zealand economy. New Zealand, a small open economy, is one of the least regulated economies in the Organisation for Economic Cooperation and Development (OECD) and without foreign exchange market interventions. To incorporate the interest rate, the exchange rate and the credit channels the model includes an inflation targeting monetary authority, imports and exports of goods and asymmetric information between borrowers and lenders.

The paper proceeds as follows. Section 2 describes the theoretical model. Section 3 discusses the adjustment of the economy to shocks. The relative importance of the transmission channels is

[1] See, for example, Ramey (1993), Ramírez (2004) and Gallegati (2005) for the credit channel and Taylor (1995), Ramaswamy and Slϕk (1998) and Angeloni, Kashyap, Mojon and Terlizzese (2003) for the interest and / or exchange rate channels. An exception is Tang (2006), who analyses the relative importance of monetary policy channels in Malaysia in a structural vector autoregression (SVAR) framework.

evaluated in section 4. Section 5 presents some sensitivity analysis and the last section summarises and concludes.

## 2 Theoretical model

This section briefly describes how the interest rate, the exchange rate and the credit channels affect the transmission of shocks in an open economy. It then develops the theoretical model that is used to assess the relative importance of the three channels. There are six agents in the model: households, firms, financial intermediaries, entrepreneurs, a government and an inflation targeting monetary authority.

### 2.1 Transmission of shocks

Following a shock to the economy the central bank adjusts interest rates to maintain its consumer price inflation target. The monetary response gives rise to the interest rate channel. A change in monetary policy is transmitted to the real economy through its impact on the cost of consumption and the rate of return to capital. Moreover, a change in interest rates affects the exchange rate.

The exchange rate channel mainly operates through net exports. Real exchange rate changes affect the cost of commodity imports, which are an input in firms' production of consumption goods. They also impact on the price of exports and the foreign demand for these products. Moreover, exchange rate movements influence full capacity output.

The credit channel arises because of asymmetric information between borrowers and lenders. Entrepreneurs, who produce capital goods, must use external financing. This leads to agency costs because entrepreneurs' production technology is subject to idiosyncratic shocks that only entrepreneurs can observe costlessly. To help overcome the information asymmetry entrepreneurs use their own net worth (internal funds) and borrow from households via financial intermediaries.

The credit channel arises from the impact of shocks on entrepreneurs' net worth and their ability to borrow from financial intermediaries to expand production.

The remainder of this section develops the model.

## 2.2 Households

Households are infinitely lived and a typical household values streams of consumption and leisure according to

$$E_t \sum_{k=0}^{\infty} \beta^k \left\{ \ln\left(C_{t+k}^h\right) + \gamma\left(1 - N_{t+k}\right) \right\} \tag{1}$$

where $\gamma > 0$ is a parameter, $\beta \in (0,1)$ is the household's discount factor and $E_t$ is a conditional expectations operator with respect to information available at time $t$. Households' time endowment is normalised to one. Their labour supply is given by $N_t$ and $(1 - N_t)$ is leisure. Each household consumes many goods, all of which are domestically produced. $C_t^h$ is the quantity consumed in period $t$ of an index of these goods with $C_t^h = \left[\int_0^1 C_t^h(j)^{(\theta-1)/\theta} dj\right]^{\theta/(\theta-1)}$, where $C_t^h(j)$ denotes the household's period $t$ consumption of good $j$ and $\theta > 0$ is the price elasticity of demand.[2] The price of consumption good $j$ is given by $P_t(j)$ and the aggregate price level, $P_t$, is an index given by $P_t = \left[\int_0^1 P_t(j)^{1-\theta} dj\right]^{1/(1-\theta)}$.

Households earn income from supplying labour, $N_t$, at wage rate $W_t^h$ and by renting physical capital, $K_{t-1}^h$, accumulated last period, to firms at rate $R_t$. Households also receive dividend payments, $\Omega_t$, from firms and earn income from holding domestic bonds issued by financial intermediaries, $B_{t-1}^h$, and foreign bonds, $B_{t-1}^{h*}$. Domestic bonds, $B_{t-1}^h$, earn a nominal return (in terms of domestic currency) of $I_t$ and the nominal rate of interest paid on foreign bonds, $B_{t-1}^{h*}$, is given by $I_t^*$. Households also hold demand deposits, $D_{t-1}$, to purchase consumption and capital

[2] Entrepreneurs' and the government's consumption indexes (discussed below) are given accordingly.

goods. Demand deposits do not earn any interest.[3] Households pay taxes on their wage and rental incomes. For simplicity, households' interest and dividend incomes and capital gains from exchange rate and capital price movements are not taxed. The tax rate imposed by the government is given by $\tau$. The typical household's budget constraint is thus given by

$$\begin{aligned}
&(1-\tau) W_t^h N_t + ((1-\delta)\Psi_t + (1-\tau) R_t) P_t K_{t-1}^h + (1+I_t) B_{t-1}^h \\
&+ (1+I_t^*) S_t B_{t-1}^{h*} + \Omega_t + D_{t-1} - P_t C_t^h - B_t^h - S_t B_t^{h*} - D_t \\
&- \Psi_t P_t K_t^h = 0
\end{aligned} \tag{2}$$

where $S_t$ denotes the nominal exchange rate, $\Psi_t$ is the price of capital in terms of consumption goods (discussed further below) and $\delta$ is the depreciation rate of capital.

The household's deposit-in-advance constraint is given by

$$P_t \left( C_t^h + \Psi_t K_t^h - (1-\delta)\Psi_t K_{t-1}^h \right) \leq D_{t-1} \tag{3}$$

and holds as an equality at an optimum if $I_t > 0$. Using equation (3), the household's budget constraint can then be re-written in real terms as

$$\begin{aligned}
&(1-\tau)\hat{W}_t^h N_t + (1-\tau) R_t K_{t-1}^h + \tfrac{(1+I_t)\hat{B}_{t-1}^h}{1+\Pi_t} + \tfrac{(1+I_t^*) Q_t \hat{B}_{t-1}^{h*}}{1+\Pi_t^*} + \hat{\Omega}_t - \hat{B}_t^h \\
&- Q_t \hat{B}_t^{h*} - (1+\Pi_{t+1}) \left( C_{t+1}^h + \Psi_{t+1} K_{t+1}^h - (1-\delta)\Psi_{t+1} K_t^h \right) = 0
\end{aligned} \tag{4}$$

The real wage rate is given by $\hat{W}_t^h$, and $\hat{B}_t^h$, $\hat{B}_t^{h*}$ and $\hat{\Omega}_t$ are the household's domestic and foreign bond holdings and dividend payments from firms in real terms. $Q_t$ denotes the real exchange rate, $Q_t \equiv S_t P_t^* / P_t$. $\Pi_t$ is the domestic inflation rate with $\Pi_t = P_t / P_{t-1} - 1$ and the foreign inflation rate is given by $\Pi_t^* = P_t^* / P_{t-1}^* - 1$, where $P_t^*$ is the aggregate foreign price level.

[3] In the analysis domestic bond holdings are assumed to be zero and, as noted, demand deposits earn no interest. These assumptions allow to abstract from financial intermediaries' budget constraint.

The household's optimisation problem consists of choosing $\left\{C_t^h,\ N_t,\ K_t^h,\ \hat{B}_t^h,\ \hat{B}_t^{h*}\right\}$ for all $t \in [0, \infty)$ to maximise lifetime utility (equation (1)) subject to equation (4). Dividends are paid at the end of each period and do not affect households' optimisation problems. Households' first-order conditions are given by

$$\frac{1}{\gamma C_t^h} - \frac{(1+I_t)}{(1-\tau)\hat{W}_t^h} = 0 \tag{5}$$

$$\frac{\Psi_t}{C_t^h} - E_t\left[\frac{\beta\left((1-\delta)\Psi_{t+1} + \frac{(1-\tau)R_{t+1}}{1+I_{t+1}}\right)}{C_{t+1}^h}\right] = 0 \tag{6}$$

and

$$E_t\left[\frac{Q_{t+1}}{Q_t}\frac{1+I_{t+1}^*}{1+\Pi_{t+1}^*} - \frac{1+I_{t+1}}{1+\Pi_{t+1}}\right] = 0 \tag{7}$$

At an optimum the marginal rate of substitution between consumption and leisure is equal to the relative price of consumption; that is, the ratio of the effective price of consumption and the after-tax real wage rate. The effective price of consumption is the sum of its market price (equal to unity) and the opportunity cost of having to hold demand deposits to purchase consumption goods, $I_t$. Further, the marginal rate of substitution between consumption today and next period is equal to the effective return from accumulating an additional unit of capital. The effective return is given by a unit value of the capital stock net of depreciation plus the after-tax rate of return on capital adjusted for the opportunity cost of having to hold demand deposits to purchase capital. Finally, real rates of return from holding domestic and foreign bonds are equal and households are indifferent between holding domestic or foreign bonds.

Equations (5) to (7) show how the interest rate channel operates through the households sector. It affects households' opportunity cost of consumption and the rental rate of capital. Moreover, a change in interest rates impacts on the exchange rate.

## 2.3 Financial intermediaries and entrepreneurs

The credit channel arises because of asymmetric information between borrowers and lenders and operates through financial intermediaries and entrepreneurs. The set-up is based on Carlstrom and Fuerst (1997). Entrepreneurs produce capital (investment) goods, which firms use as an input in the production of consumption goods. Each entrepreneur $i$ borrows $(IN_t\,(i) - NW_t\,(i))$ consumption goods from households via financial intermediaries, where $IN_t\,(i)$ is the size of entrepreneur $i$'s investment good production and $NW_t\,(i)$ is entrepreneur $i$'s net worth or internal funds. Entrepreneurs' net worth consists of their after-tax wage earnings and the market value of their capital stock. After capital is produced loans are repaid in capital goods.

Each entrepreneur $i$ has access to a stochastic technology, $\omega_t\,(i)$, that transforms an input of $IN_t$ consumption goods into $\omega_t\,(i)\,IN_t$ units of new capital. The random variable $\omega_t\,(i)$ is assumed to be lognormally distributed across time and entrepreneurs, i.e. $\ln(\omega_t\,(i)) \sim N\left(\tilde{\mu},\ \tilde{\sigma}^2\right)$, with a mean of unity and a standard deviation of $\sigma$. The distribution function and density of $\omega_t\,(i)$ are given by $\Phi\,(\omega_t\,(i))$ and $\phi\,(\omega_t\,(i))$.

Agency costs arise because lenders can only observe $\omega_t\,(i)$ at a monitoring cost of $\alpha IN_t\,(i)$ capital inputs, i.e. there is costly state verification (Townsend, 1979). The information asymmetry creates a moral hazard problem because entrepreneurs have an incentive to underreport their true value of $\omega_t\,(i)$. The optimal debt contract is structured so that entrepreneur $i$ always truthfully reports the value of $\omega_t\,(i)$. The optimal contract is risky debt and characterised by the size of entrepreneur $i$'s project, $IN_t\,(i)$, and a critical value for $\omega_t\,(i)$ that triggers bankruptcy, denoted by $\varpi_t\,(i)$. If the realisation of the technology shock $\omega_t\,(i)$ is below the critical $\varpi_t\,(i)$, the entrepreneur becomes bankrupt and defaults on the debt contract. In the event of default, the financial intermediary monitors the entrepreneur, as in Williamson (1986), confiscates all returns from the project and absorbs any losses.

To derive the optimal project size $IN_t(i)$ and the critical $\varpi_t(i)$ that triggers bankruptcy two functions, $f(\varpi)$ and $g(\varpi)$, are defined. They are the fractions of the expected net capital output received by the entrepreneur and lender. Time and entrepreneur subscripts have been dropped for simplicity. The functions are given by $f(\varpi) = \int_{\varpi}^{\infty} (\omega - \varpi) \, d\Phi(\omega) = \int_{\varpi}^{\infty} \omega d\Phi(\omega) - [1 - \Phi(\varpi)] \varpi$ and $g(\varpi) = \int_0^{\varpi} \omega d\Phi(\omega) - \alpha\Phi(\varpi) + [1 - \Phi(\varpi)] \varpi$, where $f(\varpi)$ integrates only over values of $\omega$ in excess of $\varpi$ and $g(\varpi)$ integrates over 0 to $\varpi$. Moreover, $f(\varpi)$ and $g(\varpi)$ do not sum to one because of expected bankruptcy and monitoring costs, i.e. $f(\varpi) + g(\varpi) = 1 - \alpha\Phi(\varpi)$.

The expected net capital output received by the entrepreneur and lender from entrepreneur $i$'s project is given by $f(\varpi_t(i)) \Psi_t IN_t(i)$ and $g(\varpi_t(i)) \Psi_t IN_t(i)$, where $\Psi_t$ is the aggregate price of capital in terms of consumption goods. The optimal contract between the lender and entrepreneur is given by the pair $(IN_t(i), \ \varpi_t(i))$ that maximises the entrepreneur's net capital output subject to the lender being indifferent between loaning the funds to the entrepreneur and retaining them, i.e.

$$\max f(\varpi_t(i)) \Psi_t IN_t(i) \tag{8}$$

subject to[4]

$$g(\varpi_t(i)) \Psi_t IN_t(i) \geq IN_t(i) - NW_t(i) \tag{9}$$

The first-order conditions of the optimisation problem are given by

$$\frac{f(\varpi_t(i))}{f'(\varpi_t(i))} = \frac{g(\varpi_t(i))\Psi_t - 1}{g'(\varpi_t(i))\Psi_t} \tag{10}$$

[4] At an optimum equation (9) holds as an equality.

which can be re-written as

$$\Psi_t \left(1 - \alpha\Phi\left(\varpi_t\left(i\right)\right) + \tfrac{\alpha\phi(\varpi_t(i))f(\varpi_t(i))}{f'(\varpi_t(i))}\right) = 1 \tag{11}$$

and

$$IN_t\left(i\right) = \tfrac{NW_t(i)}{1-g(\varpi_t(i))\Psi_t} \tag{12}$$

Equation (11) determines the critical $\varpi_t\left(i\right)$ as a function of the aggregate price of capital, $\Psi_t$, the distribution of the stochastic technology shock, $\omega_t\left(i\right)$, and the monitoring cost, $\alpha$. The critical $\varpi_t\left(i\right)$ is independent of $i$; that is, all entrepreneurs receive the same basic terms on their debt contract. Contracts only differ in terms of size – entrepreneurs with larger net worth receive a proportionately larger loan (equation (12)).[5] Variables specific to $i$ can henceforth be interpreted as averages.

Entrepreneurs are infinitely lived. A typical entrepreneur values streams of consumption according to

$$E_t \sum_{k=0}^{\infty} \left(\zeta\beta\right)^k C^e_{t+k} \tag{13}$$

where $C^e_t$ is an index of entrepreneurial consumption in period $t$ and $\zeta \in (0,1)$ is an additional discount factor. Entrepreneurs are assumed to discount the future more heavily than households to ensure that they use external financing. Agency costs imply that the return to internal funds is greater than the return to external funds and entrepreneurs have an incentive to postpone all consumption and accumulate internal funds to self-finance. The gross expected return to internal funds is given by $1 + IR_t = f\left(\varpi_t\right)\Psi_t IN_t/NW_t = f\left(\varpi_t\right)\Psi_t/\left(1 - g\left(\varpi_t\right)\Psi_t\right)$, where $\left(f\left(\varpi_t\right)\Psi_t IN_t\right)/NW_t$ denotes the expected net capital output received by entrepreneurs per unit of leveraged net worth.

[5] This result overcomes the heterogeneity problem with entrepreneurs that arises from the idiosyncratic technology shock. It follows from the assumption of linear monitoring costs and investment technology.

With no external financing, agency costs disappear. The additional discount factor avoids this outcome.

The typical entrepreneur's net worth, $NW_t$, in real terms is given by

$$NW_t = (1-\tau)\,\hat{W}_t^e + ((1-\delta)\,\Psi_t + (1-\tau)\,R_t)\,K_{t-1}^e \tag{14}$$

where $\hat{W}_t^e$ is the entrepreneur's real wage rate. Entrepreneurial labour supply is equal to unity and $K_{t-1}^e$ is the entrepreneur's capital stock.[6]

The entrepreneur's budget constraint is given by

$$\left((1-\tau)\,\hat{W}_t^e + ((1-\delta)\,\Psi_t + (1-\tau)\,R_t)\,K_{t-1}^e\right)\frac{f(\varpi_t)\Psi_t}{1-g(\varpi_t)\Psi_t} - C_t^e - \Psi_t K_t^e = 0 \tag{15}$$

As in the case of households, entrepreneurs' wage earnings and return to capital are taxed but capital gains from capital price movements are not. Equation (15) states that the entrepreneur's net worth, $(1-\tau)\,\hat{W}_t^e + ((1-\delta)\,\Psi_t + (1-\tau)\,R_t)K_{t-1}^e$, earns an expected return to internal funds of $f(\varpi_t)\,\Psi_t/\,(1-g(\varpi_t)\,\Psi_t)$. The entrepreneur uses a proportion of the newly created capital to purchase consumption goods, $C_t^e$, and $K_t^e$ denotes the entrepreneurial capital left after consumption.

The entrepreneur's optimisation problem consists of choosing $\{C_t^e,\ K_t^e\}$ for all $t \in [0,\infty)$ to maximise lifetime utility (equation 13) subject to equation (15). The entrepreneur's first-order condition is given by

$$\Psi_t = E_t\left[\frac{\zeta\beta((1-\delta)\Psi_{t+1}+(1-\tau)R_{t+1})f(\varpi_{t+1})\Psi_{t+1}}{1-g(\varpi_{t+1})\Psi_{t+1}}\right] \tag{16}$$

The term $f(\varpi_{t+1})\,\Psi_{t+1}/\,(1-g(\varpi_{t+1})\,\Psi_{t+1})$ in equation (16) is the gross expected return on internal funds, $1+IR_{t+1}$, and is greater than one. It is this additional return that encourages

[6] The assumption of entrepreneurial labour income ensures that entrepreneurs always have a nonzero level of net worth.

entrepreneurs to accumulate capital even though they discount the future more than households. To avoid self-financing, in the calibration $\zeta$ is set to offset the steady state internal return, i.e. $\zeta f(\bar{\varpi})\bar{\Psi}/\left(1-g(\bar{\varpi})\bar{\Psi}\right)=1$.[7]

## 2.4 Firms

Firms are monopolistic competitors and specialise in production. A typical firm produces output of consumption good $j$, $Y_t(j)$, under a constant elasticity of substitution (CES) technology by hiring household and entrepreneurial labour, $L_t^h(j)$ and $L_t^e(j)$, using capital, $K_{t-1}(j)$, and commodity inputs, $IM_t(j)$. Production inputs are purchased in competitive factor markets. Firms rent the capital from households and entrepreneurs and import the commodity inputs at the beginning of each period. Firm $j$'s production function is given by

$$\begin{aligned} Y_t(j) &= [(\eta_l\left(Z_t L_t^h(j)\right)^{\nu}+\eta_k\left(K_{t-1}(j)\right)^{\nu} \\ &+\eta_{im}\left(IM_t(j)\right)^{\nu}+\left(1-\eta_l-\eta_k-\eta_{im}\right)\left(L_t^e(j)\right)^{\nu}]^{\frac{1}{\nu}} \end{aligned} \quad (17)$$

where $\eta_l$, $\eta_k$, $\eta_{im}\in(0,1]$ are parameters and $\nu<1$; that is, the marginal return to each input is diminishing. $Z_t$ denotes aggregate productivity and the elasticity of substitution in production is given by $1/(1-\nu)$.

The assumption of monopolistic competition in the consumption goods market allows pricing decisions to be determined explicitly, which is necessary to introduce nominal rigidities. A firm treats the price in domestic currency, $P_t(j)$, of the consumption good $j$ it produces as a choice variable, while taking the domestic aggregate price level, $P_t$, the nominal exchange rate, $S_t$, and the foreign price level, $P_t^*$, as given. Having chosen $P_t(j)$, the firm then produces the quantity of output demanded at that price.[8]

[7] Letters with a " $^{-}$ " indicate (average) steady state levels.

[8] Firms may not price discriminate and the price of good $j$ sold to foreign consumers (denominated in foreign

Each firm sells its output of consumption good, $Y_t(j)$, to domestic households, $C_t^h(j)$, entrepreneurs, $C_t^e(j)$, and the government, $G_t(j)$. Firms also export to the rest of the world, $EX_t(j)$. The demand functions for good $j$ are given by $C_t^h(j) = (P_t(j)/P_t)^{-\theta} C_t^h$, $C_t^e(j) = (P_t(j)/P_t)^{-\theta} C_t^e$ and $G_t(j) = (P_t(j)/P_t)^{-\theta} G_t$, where $C_t^h$, $C_t^e$ and $G_t$ are total consumption by the typical household and entrepreneur and the government. Similarly, foreign demand for consumption good $j$ is given by $EX_t(j) = (P_t(j)/P_t)^{-\theta} EX_t$, where $EX_t$ denotes aggregate exports. $EX_t$ is a function of the real exchange rate, $Q_t$, and foreign demand for the domestic country's output, $Y_t^*$, and given by

$$EX_t = (Q_t)^{\kappa} (Y_t^*)^{\varsigma} \tag{18}$$

where $\kappa$, $\varsigma > 0$ are the price and foreign demand elasticities of exports.[9]

Firm $j$ chooses $\left\{P_t(j),\ L_t^h(j),\ L_t^e(j),\ IM_t(j),\ K_{t-1}(j)\right\}$ to maximise profits subject to its production function (17) and demand function, $Y_t(j) = (P_t(j)/P_t)^{-\theta} Y_t$. Profits, $\Theta_t(j)$, are given by

$$\begin{aligned}\Theta_t(j) &= \left[P_t(j) Y_t(j) - W_t^h L_t^h(j) - W_t^e L_t^e(j) - R_t P_t K_{t-1}(j) - S_t P_t^* IM_t(j)\right] \\ &= \left[P_t(j) - P_t MC_t\right] \left(\frac{P_t(j)}{P_t}\right)^{-\theta} Y_t\end{aligned} \tag{19}$$

where $MC_t$ is the real marginal cost. Firm $j$'s first-order conditions are given by $P_t(j) = (\theta/(\theta-1)) P_t MC_t$, $W_t^h/P_t(j) = \eta_l (Z_t)^{\nu} \left(Y_t(j)/L_t^h(j)\right)^{1-\nu} / (\theta/(\theta-1))$, $W_t^e/P_t(j) = (1-\eta_l-\eta_k-\eta_{im}) (Y_t(j)/L_t^e(j))^{1-\nu} / (\theta/(\theta-1))$, $P_t R_t/P_t(j) = \eta_k (Y_t(j)/K_{t-1}(j))^{1-\nu} / (\theta/(\theta-1))$ and $S_t P_t^*/P_t(j) = \eta_{im} (Y_t(j)/IM_t(j))^{1-\nu} / (\theta/(\theta-1))$. In a symmetric equilibrium, all firms charge the same price, produce the same output, employ the same labour and use the

currency) is given by $P_t(j)/S_t$.

[9] The domestic economy's exports are assumed to form an insignificant proportion of foreigners' demand and have a negligible weight in the rest of the world's price index, that is the small economy assumption.

same capital and commodity inputs. The first-order conditions can then be re-written as

$$MC_t = \frac{1}{\frac{\theta}{\theta-1}} \tag{20}$$

$$\hat{W}_t^h = \frac{\eta_l (Z_t)^{\nu} \left(\frac{Y_t}{L_t^h}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{21}$$

$$\hat{W}_t^e = \frac{(1-\eta_l-\eta_k-\eta_{im}) \left(\frac{Y_t}{L_t^e}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{22}$$

$$R_t = \frac{\eta_k \left(\frac{Y_t}{K_{t-1}}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{23}$$

and

$$Q_t = \frac{\eta_{im} \left(\frac{Y_t}{IM_t}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{24}$$

The first-order conditions (21) to (24) show that firms sell their output of consumption goods at a mark-up over production costs and factor prices are below their marginal products. Under price flexibility the mark-up is constant and equal to $\theta/(\theta-1)$. Under price stickiness it is given by $\xi_t$. The mark-up gives rise to economic profits of $(\xi_t - 1) Y_t/\xi_t$, which are paid to households as dividends, $\hat{\Omega}_t$, at the end of each period.

The exchange rate channel mainly operates through firms' net exports. Real exchange rate movements influence the supply and demand of final products and factors of production. A change in the exchange rate affects the cost of production through its impact on the price of imported inputs. It also affects the price of exports and the foreign demand for firms' output.

## 2.5 Government

The government collects taxes on households' and entrepreneurs' wage and rental incomes, $\tau\left(\hat{W}_t^h L_t^h + \hat{W}_t^e L_t^e + R_t K_{t-1}\right)$. It uses this revenue to purchase an index of consumption goods,

$G_t$, from firms. For simplicity, the government's budget constraint is assumed to balance in each period

$$\tau\left(\hat{W}_t^h L_t^h + \hat{W}_t^e L_t^e + R_t K_{t-1}\right) - G_t = 0 \tag{25}$$

i.e. there is no debt financing.[10]

## 2.6 Monetary authority

The monetary authority has an explicit consumer price inflation target, $\Pi^T$. To maintain this target following a shock to the economy the central bank adjusts the nominal rate of interest paid on domestic bonds. Its reaction function is based on a variant of the Taylor rule (Taylor, 1993) and depends on deviations of inflation from target and deviations of output from full capacity, flexible price output as in a Taylor rule, and last period's interest rate. Full capacity, flexible price output and the central bank's reaction function are discussed further in section 3.

## 2.7 Equilibrium conditions

The clearing conditions are given by

$$L_t^h = (1-\eta)\, N_t \tag{26}$$

$$L_t^e = \eta \tag{27}$$

$$Y_t = (1-\eta)\, C_t^h + \eta C_t^e + G_t + EX_t + \eta IN_t \tag{28}$$

$$K_t = K_t^h + K_t^e \tag{29}$$

[10] Taxation affects households' labour-leisure choices and households' and entrepreneurs' capital accumulation decisions. The investigation of the real effects of this distortionary taxation is left for future work.

and

$$K_t = (1-\delta) K_{t-1} + \eta IN_t \left(1 - \alpha \Phi\left(\varpi_t\right)\right) \tag{30}$$

where the proportion of households is given by $(1-\eta)$ and that of entrepreneurs by $\eta$, i.e. households and entrepreneurs form a continuum of agents with unit mass. Moreover, entrepreneurial labour supply is equal to unity.

The current account balance is given by

$$CA_t = EX_t - Q_t IM_t \tag{31}$$

Uncovered interest rate parity holds

$$1 + I_t = E_t \left[ \left(1 + I_t^*\right) \frac{S_{t+1}}{S_t} \right] \tag{32}$$

and implies that households are indifferent between holding domestic or foreign bonds. The real exchange rate, $Q_t$, evolves according to

$$E_t \left[ \frac{Q_{t+1}}{Q_t} \right] = E_t \left[ \frac{\frac{S_{t+1}}{S_t} \frac{P_{t+1}^*}{P_t^*}}{\frac{P_{t+1}}{P_t}} \right] \tag{33}$$

and the sequences of the foreign interest rate, prices, inflation and foreign demand $\{I_t^*,\ P_t^*,\ \Pi_t^*,\ Y_t^*\}$ are given to the small open economy.

### 2.8 Parameterisation of the model

A period in the model is assumed to correspond to one quarter. Parameter values are chosen so that the steady state of the baseline model is broadly consistent with New Zealand data and/or assumptions made in the literature.

Households' discount rate, $\beta$, equals 0.9902 and leads to an annual steady state, real domestic interest rate of 4 percent. The coefficient on leisure, $\gamma$, in households' utility function is chosen so that their work effort accounts for a third of their time endowment in steady state. The ratio of entrepreneurs to households, $\eta$, is arbitrarily set to 0.1.

The entrepreneurs' extra discount factor, $\zeta$, is 0.947 and the monitoring cost, $\alpha$, is 0.25. The bankruptcy rate, $\Phi(\bar{\varpi})$, equals 0.974 percent per quarter and the standard deviation of the idiosyncratic technology shocks, $\sigma$, is 0.207. These assumptions are the same as in Carlstrom and Fuerst (1997).

Labour-augmenting productivity, $\bar{Z}$, is normalised to 1 in steady state. The elasticity of substitution between labour, capital and commodity inputs, $1/(1-\nu)$, is set to 0.85 in line with estimates for New Zealand by Hall and Scobie (2005). The coefficients on household labour, $\eta_l$, capital, $\eta_k$, and commodity inputs, $\eta_{im}$, in firms' production function are 0.5399, 0.36 and 0.1 respectively. These assumptions are broadly in line with New Zealand input-output data for 1995-96 and yield a steady state ratio of imports to output of about 12 percent, the same as in McCallum and Nelson (1999).[11] The capital depreciation rate equals 8.5 percent per annum, the same as in the Reserve Bank's model and firms' mark-up in steady state is 20 percent ($\theta/(\theta-1) = 1.2$), i.e. $\theta = 6$, the same as in McCallum and Nelson (1999).

The annual domestic steady state inflation rate, $\Pi^T$, of 2 percent is equal to the mid-point of the Reserve Bank of New Zealand's 1 to 3 percent target band for consumer price inflation. The tax rate, $\tau$, equals 17 percent in line with the income tax assumption in the Reserve Bank's model. The steady state foreign inflation rate, $\bar{\Pi}^*$, and nominal bond rate, $\bar{I}^*$, are assumed to be the same as for the domestic economy and the steady state real exchange rate, $\bar{Q}$, is normalised to 1. The

[11] The steady state ratio of imports to output is lower than in the Reserve Bank of New Zealand's macroeconomic model (Black, Cassino, Drew, Hansen, Hunt, Rose and Scott, 1997) because in this model all imports are intermediate goods whereas in the Reserve Bank's model a proportion of imports is for final demand.

price and foreign demand elasticities of exports, $\kappa$ and $\varsigma$, are equal to unity, as in McCallum and Nelson (2000). Foreign demand is chosen to yield a steady state ratio of exports to output of 11 percent, the same as in McCallum and Nelson (1999), leading to a current account deficit of around $-1$ percent of steady state output.

## 3 Adjustment of the economy to shocks

To evaluate the relative importance of the interest rate, the exchange rate and the credit channels in the transmission of shocks, the economy is subjected to a range of exogenous shocks. The relative contribution of each transmission channel is determined by comparing the impulse responses when the relevant channel is shutdown with the impulse responses when all three channels are operating. This approach is borrowed from empirical vector autoregression literature.[12]

The dynamic responses are derived in terms of logarithmic deviations from steady state (denoted by lower case letters). Analysing the dynamic properties of the model requires specifying the inflation process, full capacity, flexible price output, the monetary authority's reaction function and the shock processes.

### 3.1 Inflation process

The inflation process is derived from firms' optimal price setting following Calvo (1983). With probability $\varphi$, firms can adjust their prices each period. Here, $\varphi$ is set to 0.33, i.e. prices remain unchanged on average for three quarters.

Following Rotemberg (1987), the representative firm $j$ sets its price to minimise a quadratic loss function that depends on the difference between the firm's actual price in period $t$ and its target price. The firm's target price, $\tilde{P}_t(j)$, is the price that the firm would set in the absence of

[12] See, for example, Ramey (1993), Dungey and Pagan (2000) and Ludvigson, Steindel and Lettau (2002).

restrictions to adjust prices. It is given by $\tilde{P}_t(j) = \theta/(\theta-1) P_t MC_t$ or in logarithmic deviations from steady state as $\tilde{p}_t(j) = p_t + mc_t$. Firm $j$'s quadratic loss function and first-order condition with respect to $p_t(j)$ are given[13]

$$\min \tfrac{1}{2} \sum_{k=0}^{\infty} (1-\varphi)^k \beta^k E_t \left[p_t(j) - \tilde{p}_{t+k}(j)\right]^2 \tag{34}$$

and

$$p_t(j) = (1-(1-\varphi)\beta)\, \tilde{p}_t(j) + (1-\varphi)\beta E_t\left[p_{t+1}(j)\right] \tag{35}$$

If the number of firms is large, a fraction of firms $\varphi$ actually adjusts prices each period and the aggregate price adjustment equation can be derived from equation (35) as $\pi_t = \beta E_t[\pi_{t+1}] + \varphi(1-(1-\varphi)\beta)/(1-\varphi)\, mc_t$, where $\pi_t = p_t - p_{t-1}$. That is, inflation is a function of expected future inflation and real marginal cost. Under price stickiness, the marginal cost, $MC_t$, is equal to the inverse of firms' mark-up, $\xi_t$, i.e. $MC_t = 1/\xi_t$. Using $\xi_t/(\theta/(\theta-1)) = \xi_t P_t MC_t/(\theta/(\theta-1) P_t MC_t) = P_t/\tilde{P}_t(j)$, $\tilde{Y}_t(j) = \left(\tilde{P}_t(j)/P_t\right)^{-\theta} Y_t$, and dropping the $j$'s (as all firms charge the same price and produce the same output in a symmetric equilibrium) the log real marginal cost, $mc_t$, can be derived as $mc_t = -(y_t - \tilde{y}_t)/\theta$. The inflation adjustment equation then is given by

$$\pi_t = \beta E_t[\pi_{t+1}] + \varrho(y_t - \tilde{y}_t) \tag{36}$$

where $\varrho = \varphi(1-(1-\varphi)\beta)/\theta(1-\varphi)$ and $\tilde{y}_t$ denotes full capacity, flexible price output. Equation (36) thus states that inflation is determined by expected future inflation and the output gap, i.e. deviations of output from flexible price, full capacity output.

[13] Firms' discount factor, $\beta$, is assumed to be the same as for households.

### 3.2 Full capacity, flexible price output

Full capacity, flexible price output, $\tilde{y}_t$, is the total domestic output of consumption goods that would be produced under price flexibility. In that case firms' mark-up is constant and output is given by

$$\tilde{y}_t = \eta_l \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu z_t + \eta_l \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu \tilde{l}_t^h + \eta_k \left(\frac{\bar{K}}{\bar{Y}}\right)^\nu \tilde{k}_t + \eta_{im} \left(\frac{\bar{IM}}{\bar{Y}}\right)^\nu \tilde{im}_t \tag{37}$$

where $\tilde{l}_t^h$, $\tilde{k}_t$ and $\tilde{im}_t$ denote flexible price household labour, capital and commodity imports.[14] Flexible price household labour, $\tilde{l}_t^h$, can be derived from households' first-order condition that the marginal utility of leisure is equal to the after-tax real wage rate and firms' first-order condition determining labour demand (equation 21). It is given by $\tilde{l}_t^h = \tilde{y}_t + \nu/(1-\nu) z_t$. Flexible price capital, $\tilde{k}_t$, and commodity imports, $\tilde{im}_t$, are derived from firms' first-order conditions (23) and (24) and are given by $\tilde{k}_t = \tilde{y}_t - 1/(1-\nu) r_t$ and $\tilde{im}_t = \tilde{y}_t - 1/(1-\nu) q_t$. Equation (37) can then be re-written as

$$\tilde{y}_t = \frac{1}{1-\nu} z_t - \frac{\eta_k \left(\frac{\bar{K}}{\bar{Y}}\right)^\nu}{\eta_l (1-\nu) \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu} r_t - \frac{\eta_{im} \left(\frac{\bar{IM}}{\bar{Y}}\right)^\nu}{\eta_l (1-\nu) \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu} q_t \tag{38}$$

Full capacity, flexible price output is thus a function of labour-augmenting productivity, the rental rate of capital and the real exchange rate. Equation (38) thus shows that in addition to net exports the exchange rate channel also operates through full capacity, flexible price output.

### 3.3 Monetary authority's reaction function

The monetary authority's reaction function is given by

$$i_t = \mu_1 \pi_t + \mu_2 (y_t - \tilde{y}_t) + \mu_3 i_{t-1} \tag{39}$$

[14] Entrepreneurial labour input is equal to $\eta$ for all $t$ and drops out.

The coefficients on inflation, the output gap and the past interest rate are given by $\mu_1 = 1.5$, $\mu_2 = 0.5$ and $\mu_3 = 0.8$. The choice for $\mu_1$ and $\mu_2$ is based on the parameter values in a Taylor rule (Taylor, 1993).[15] The coefficient on the lagged interest rate, $\mu_3$, is the same as in McCallum and Nelson (1999) and in line with estimates for New Zealand by Huang, Margaritis and Mayes (2001), who find strong evidence of interest rate smoothing.

## 4 Business cycle effects

To illustrate the effects of the interest rate, exchange rate and the credit channels, two shocks are presented: to aggregate productivity and to foreign demand. The two shocks were chosen for two reasons. First, one is a domestic shock and the other is a foreign shock. Second, the two shocks should lead to opposite effects on inflation. The labour-augmenting productivity shock is expected to temporarily lower inflation, while the foreign demand shock should produce upward pressure on inflation.

Productivity, $z_t$, and foreign demand, $y_t^*$, are univariate exogenous processes with normally distributed errors and evolve according to

$$z_t = \rho_z z_{t-1} + \epsilon_{z,t}, \quad \text{where} \quad \epsilon_{z,t} \sim i.i.d.\ N\left(0; \sigma_z^2\right) \tag{40}$$

$$y_t^* = \rho_{y^*} y_{t-1}^* + \epsilon_{y^*,t}, \quad \text{where} \quad \epsilon_{y^*,t} \sim i.i.d.\ N\left(0; \sigma_{y^*}^2\right) \tag{41}$$

The autocorrelation coefficient of both processes are assumed to be 0.95, i.e. $\rho_{y^*} = \rho_z = 0.95$. The innovation variances are given by $\sigma_z^2 = (0.007)^2$ and $\sigma_{y^*}^2 = (0.02)^2$.

The impulse responses to a positive productivity shock and a positive foreign demand shock are plotted in Figures 1 and 2. They are in percent deviations from steady state. The solid thick line

[15] The original Taylor rule does not include the lagged interest rate.

shows the responses in the baseline model with all three channels operating. The solid thin line plots the adjustment paths of the economy without the interest rate channel and the light dotted line of the economy without the exchange rate channel. The dark dotted line shows the impulse responses of the economy without the credit channel. All variables eventually return to steady state. The log-linearised model was solved with the method of undetermined coefficients.[16]

## 4.1 Productivity shock

A positive shock to labour-augmenting productivity (Figure 1) produces an increase in output and employment in all four models. Investment, imports, consumption and output are also higher, except in the model with no interest rate channel. Moreover, the effects are smaller in the model with no exchange rate channel. This is because, with the exchange rate channel shutdown, the exchange rate no longer appreciates following the positive supply shock, leading to a smaller increase in imports, output and the current account deficit.

The positive supply shock is initially accommodated by the monetary authority and the interest rate falls in the baseline model and the model with no exchange rate channel. The interest rate falls because the positive supply shock produces a negative output gap that puts downward pressure on inflation. The negative output gap arises as actual output increases more slowly than flexible price output. Actual output rises more slowly because investment only increases with a lag. The delayed response in investment results because of the credit channel. Entrepreneurs must accumulate net worth to expand production but their capital stock is initially fixed.[17] Moreover, the positive supply shock increases the demand and price for capital, dampening further the rise in actual output. Eventually, the negative output gap is followed by a small positive gap. Inflation rises and

[16] Uhlig's (1999) procedures for MATLAB are used. The log-linearised equations of the baseline model are given in the appendix.

[17] An increase in the price and rental rate of capital, the value of entrepreneurs' capital and net worth raises the return to internal funds. The higher return to internal funds leads entrepreneurs to reduce consumption and accelerates their accumulation of capital and net worth.

the central bank tightens monetary policy.

In the model with no credit channel, entrepreneurs do not need to accumulate net worth to expand production following the positive productivity shock. As a result, the increase in actual output is instantaneous and larger than in flexible price output. This leads to an immediate tightening in monetary policy as the output gap becomes positive. Turning off the credit channel thus illustrates the importance of the credit channel for the central bank's response. The credit channel leads to a larger decline in interest rates following a positive supply shock because it dampens the magnitude of the output response.

When the interest rate channel is suppressed, the central bank no longer responds to the positive productivity shock and output increases by less. Turning off the monetary response leads to large and persistent deviations from steady state in the inflation and exchange rates with consequent adverse effects on the real economy. Following the positive productivity shock, the real exchange rate depreciates rather than appreciates. This produces a rise in exports (and a decline in the current account deficit). The rise in exports comes at the expense of domestic demand – lower aggregate consumption and investment. Moreover, the depreciation of the exchange rate dampens the rise in output as it raises the cost of imports, which are a production input. The depreciation of the real exchange rate causes a decline in flexible price output, a positive output gap and a sharp rise in inflation. The results thus show, when the interest rate channel is turned off, the benefits of the positive productivity shock are substantially reduced.

### 4.2 Foreign demand shock

Figure 2 gives the impulse responses to the foreign demand shock. Overall, the foreign demand shock has more similar effects in all four models than the responses to the productivity shock. This reflects the fact that the shock only affects a proportion of output, which is exports.

Figure 1: Impulse responses to a productivity shock (in percent deviations from steady state)

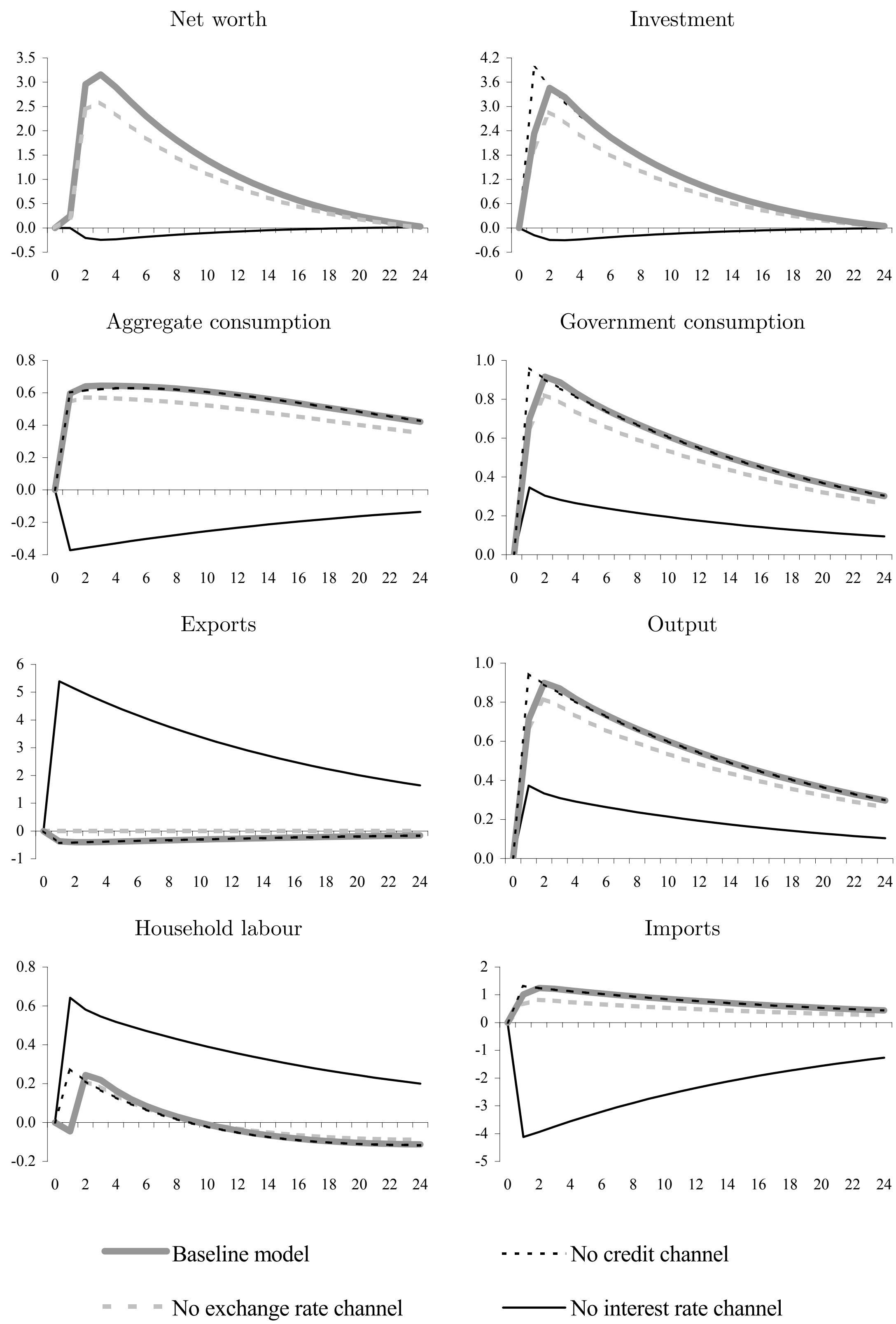
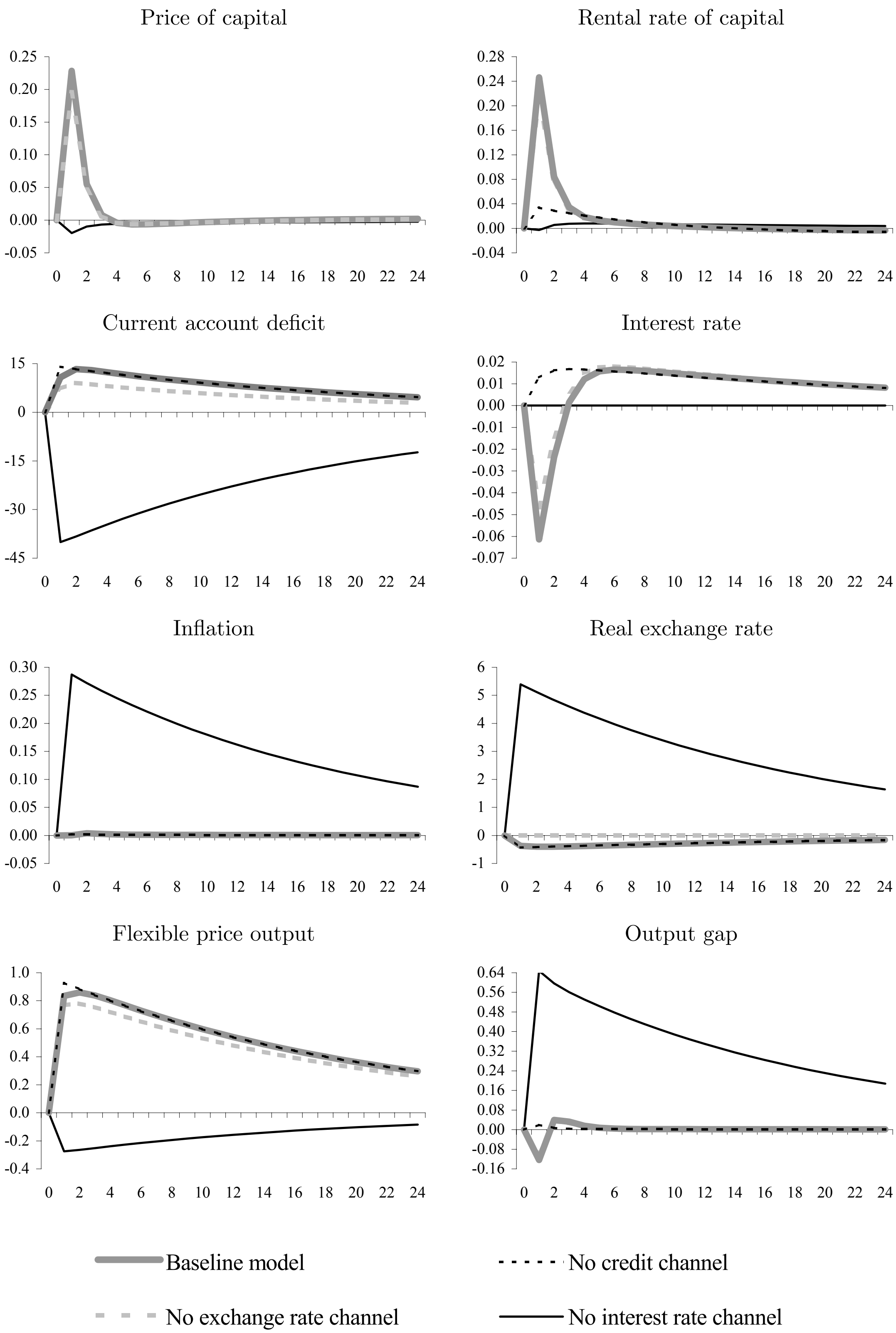


Figure 1 continued



Following the positive foreign demand shock exports rise, leading to an increase in output and employment and a decline in investment and consumption. The increase in output produces a positive output gap, inflationary pressures and a tightening in monetary policy, except for in the model with no interest rate channel. Higher interest rates are followed by an appreciation of the real exchange rate, apart from the no exchange rate channel model, and flexible price output increases, apart from the no interest rate channel model. But the rise in flexible price output is insufficient to meet increased foreign demand, leading to the positive output gap and inflationary pressures.

The real appreciation of the domestic currency leads to an increase in imports and a substitution from domestic factors of production (labour and capital) to foreign factors (imports). However, exports increase by more following the positive foreign demand shock than imports and the current account deficit falls. The current account deficit declines by more when the interest rate channel is shutdown. This is because the non responsiveness of the interest rate leads to a sharp rise in inflation and depreciation of the real exchange rate. As in the case of the productivity shock, the benefits of the positive shock are partly offset when the interest rate channel is turned off as the depreciation of the real exchange rate increases the cost of production and lowers output.

The output effects are smaller in the no exchange rate channel model and the current account deficit falls by more than in the baseline model. This is because the real exchange rate no longer appreciates following the tightening in monetary policy, leading to a smaller increase in imports and output (and larger rise in exports) than in the baseline model.

The results also illustrate how the output effects of the positive demand shock are magnified by the credit channel (whereas they were dampened in the case of the positive productivity shock). Output increases by more in the presence of the credit channel because the price of capital and hence the cost of production falls. Without the credit channel the price of capital is unaffected by the foreign demand shock. Output increases by less, requiring a smaller increase in interest rates.

Figure 2: Impulse responses to a foreign demand shock (in percent deviations from steady state)

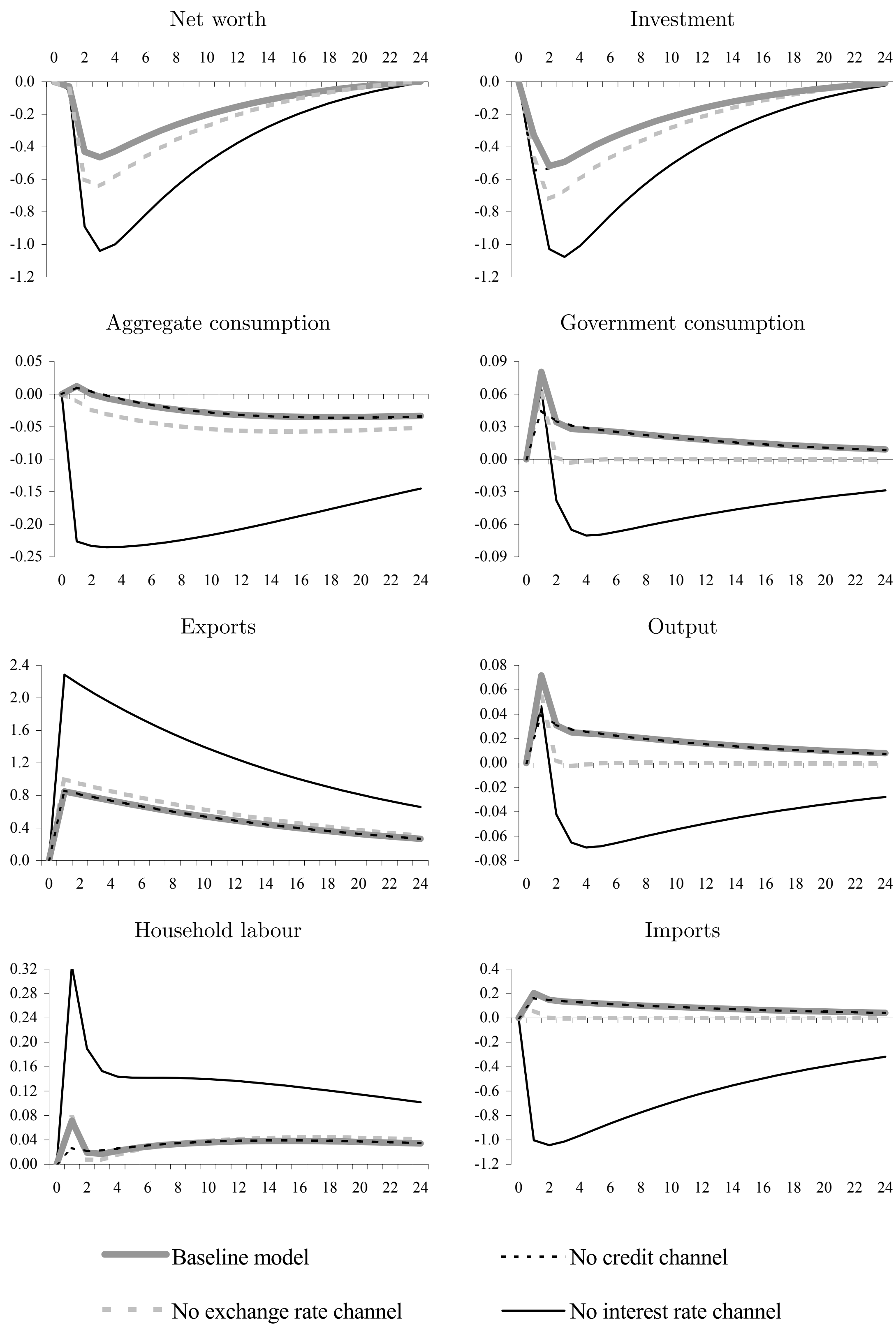
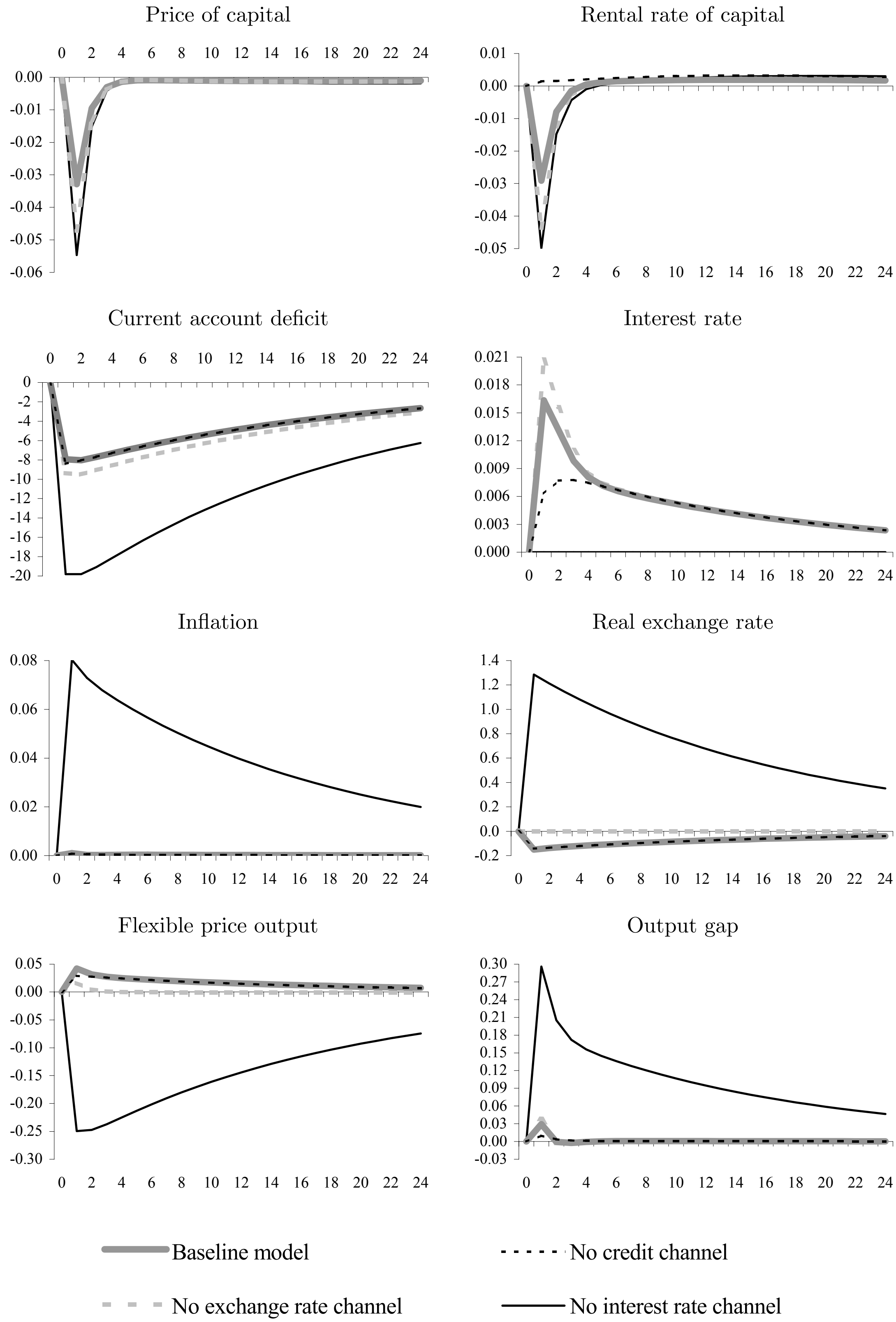


Figure 2 continued



# 5 Sensitivity analysis

The finding that all three channels affect the transmission mechanisms of shocks is robust to different specifications of the model. This section presents some sensitivity analysis.[18] The focus is on the price elasticity of demand, inflation expectations and the foreign sector. With different specifications of the model, the credit channel continues to have an important influence on the central bank's response to shocks and the output effects are smaller when the exchange rate channel is switched off. But the sensitivity analysis also shows that, when the interest rate channel is turned off, the adjustment paths of the economy crucially depend on the inflation process and the structure of the economy. These findings are discussed next.

## 5.1 Price elasticity of demand

To assess the robustness of the results, we assume a higher price elasticity of demand. The price elasticity of demand is increased from 6 to 21, which lowers firms' mark-up from 20 to 5 percent and substantially reduces the degree of monopolistic competition.

The main effect of a lower degree of monopolistic competition is on inflation. With a price elasticity of demand of 21 the demand curves facing firms become more horizontal and the coefficient on the output gap in the inflation adjustment equation approaches zero. This means that firms' price setting behaviour is less influenced by economic conditions and the inflation adjustment process is less sluggish. This has important implications for the model without the interest rate channel. Reduced inflation rigidity leads to a smaller increase in inflation and depreciation of the real exchange rate and the adjustment paths of the model without the interest rate channel are closer to those of the baseline model. The importance of the interest rate channel and hence monetary response thus decline with increasing price flexibility.

[18] The results and supporting figures are not presented but are available on request from the corresponding author.

### 5.2 Inflation expectations

The assumption in the benchmark model is that inflation expectations are formed rationally, that is, they are forward looking and model consistent. Following the Reserve Bank of New Zealand's approach for modelling inflation expectations (see Black et al., 1997) the assumption is relaxed by introducing an autoregressive term into the inflation process. This makes the inflation process partially backward looking as in Fuhrer and Moore (1995), where price rigidities arise from staggered wages.[19]

The main effect of partially backward looking inflation expectations is to make the inflation adjustment more sluggish. This has the opposite effects on the model without the interest rate channel to increasing the price elasticity of demand. Fluctuations in the inflation and exchange rates become larger and output increases by less than in the benchmark model.

### 5.3 Foreign sector

Finally, the effect of the foreign sector is assessed. In the benchmark model the foreign sector is incorporated through imports and exports of goods. Firms import a production input and export part of their output of consumption goods. To assess the effects of the foreign sector, the coefficient on commodity imports in firms' production function is reduced from 0.1 to 0.01 and the steady state ratio of exports to output is lowered from 0.11 to 0.011.

The analysis illustrates that the size of foreign trade has important implications for the model with no interest rate channel. As in the benchmark model, a shock to the economy leads to large and persistent deviations of the exchange rate (and inflation) from steady state. But because the share of imports in production has declined, the depreciation of the real exchange rate, and hence increase in the cost of imports and production, has a smaller impact on output. As a result,

[19] The coefficient on next period's inflation is $(1 - \upsilon)\,\beta$ and the coefficient on last period's inflation is $\upsilon\beta$, where $\upsilon$ is equal to 0.1.

following a positive productivity shock output no longer increases by less compared to the baseline model and the models without the credit and exchange rate channels. In fact, output increases by more as exports rise with the depreciation of the domestic currency. Output also increases faster following a positive foreign demand shock. This is because the depreciation of the real exchange rate leads to a larger rise in exports (in terms of log deviations from steady state) without the interest rate channel.

## 6 Concluding remarks

This paper developed a dynamic general equilibrium model to assess the relative importance of the interest rate, the exchange rate and the credit channels in transmitting shocks to the economy. The model was calibrated for New Zealand, a small, open and deregulated economy. The relative contribution of each transmission channel was determined by comparing the impulse responses when the relevant channel is suppressed with the impulse responses when all three channels are operating.

The analysis showed that all three channels affect the transmission mechanisms of shocks and this result is robust to different specifications of the model. Switching off the interest rate channel leads to large and persistent deviations from steady state in the inflation and exchange rates with consequent effects on the real economy. Turning off the interest rate channel thus illustrates the importance of interest rates for monetary policy to return the economy to equilibrium. The credit channel also has important real effects that impact on the central bank's response to shocks. The credit channel dampens output fluctuations following a supply shock, whereas it magnifies them following a demand shock. As a result, a larger decline (increase) in interest rates is required following a positive supply (demand) shock. The exchange rate also tends to magnify output fluctuations. This is because the exchange rate appreciation following a positive supply or demand shock lowers the price of imports and the cost of production. Overall, the findings suggest that all three channels contribute to business cycle fluctuations and the transmission of shocks to the economy. But sensitivity analysis showed that the magnitude of the impact of the interest rate channel crucially depends on the inflation process and the structure of the economy.

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# A Dynamic model

The dynamic baseline model is described by (36), (38) and (39) and the following equations:

$$(1-\nu)\,y_t - (1-\nu)\,l_t^h - c_t^h + \nu z_t + \tfrac{1}{\theta}\left(y_t - \tilde{y}_t\right) - i_t = 0$$

$$\bar{K}k_t - (1-\delta)\,\bar{K}k_{t-1} - \bar{IN}\left(1-\alpha\Phi\left(\bar{\varpi}\right)\right)in_t + \bar{IN}\alpha\phi\left(\bar{\varpi}\right)\bar{\varpi}\boldsymbol{\varpi}_t = 0$$

$$\frac{(1-\tau)(1-\nu)\eta_k\left(\frac{\bar{Y}}{\bar{K}}\right)^{1-\nu}}{\frac{\theta}{\theta-1}}y_t + (1-\delta)\,\bar{\Psi}\psi_t - \frac{(1-\tau)(1-\nu)\eta_k\left(\frac{\bar{Y}}{\bar{K}}\right)^{1-\nu}}{\frac{\theta}{\theta-1}}k_{t-1}$$
$$+\frac{(1-\tau)\eta_k\left(\frac{\bar{Y}}{\bar{K}}\right)^{1-\nu}}{\frac{\theta^2}{\theta-1}}\left(y_t-\tilde{y}_t\right) - \left(1+(1-\tau)\,\bar{R}\right)r_t = 0$$

$$\frac{(1-\eta)\bar{C}^h}{\eta}c_t^h + \bar{C}^e c_t^e + \bar{G}g_t + \bar{EX}ex_t + \bar{IN}in_t - \bar{Y}y_t = 0$$

$$\frac{1}{\bar{\Psi}}\psi_t + \frac{f(\bar{\varpi})}{f'(\bar{\varpi})}\left(\frac{\phi'(\bar{\varpi})}{\phi(\bar{\varpi})} - \frac{f''(\bar{\varpi})}{f'(\bar{\varpi})}\right)\alpha\phi\left(\bar{\varpi}\right)\bar{\varpi}\boldsymbol{\varpi}_t = 0$$

$$ir_t + nw_t - \psi_t - \frac{f'(\bar{\varpi})\bar{\varpi}}{f(\bar{\varpi})}\boldsymbol{\varpi}_t - in_t = 0$$

$$\frac{(1-\tau)(1-\nu)(1-\eta_l-\eta_k-\eta_{im})\bar{Y}^{1-\nu}}{\frac{\theta}{\theta-1}} y_t + \frac{(1-\tau)(1-\eta_l-\eta_k-\eta_{im})\bar{Y}^{1-\nu}}{\frac{\theta^2}{\theta-1}} (y_t - \tilde{y}_t)$$

$$+ \left(1 + (1-\tau)\bar{R}\right) \bar{K}^e k_{t-1}^e + \left(1 + (1-\tau)\bar{R}\right) \bar{K}^e r_t - \bar{NW} nw_t = 0$$

$$\bar{NW}\left(1 + \bar{IR}\right) nw_t + \bar{NW}\left(1 + \bar{IR}\right) ir_t - \bar{C}^e c_t^e - \bar{\Psi}\bar{K}^e \psi_t - \bar{\Psi}\bar{K}^e k_t^e = 0$$

$$\frac{1}{1-g(\bar{\varpi})\bar{\Psi}} \psi_t + \left(\frac{g'(\bar{\varpi})\bar{\Psi}}{1-g(\bar{\varpi})\bar{\Psi}} + \frac{f'(\bar{\varpi})}{f(\bar{\varpi})}\right) \bar{\varpi} \boldsymbol{\varpi}_t - ir_t = 0$$

$$\eta_l \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu z_t + \eta_l \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu l_t^h + \eta_k \left(\frac{\bar{K}}{\bar{Y}}\right)^\nu k_{t-1} + \eta_{im} \left(\frac{\bar{IM}}{\bar{Y}}\right)^\nu im_t - y_t = 0$$

$$\frac{\tau\left(\bar{Y} - \eta_{im}(1-\nu)\bar{Y}^{1-\nu}\bar{IM}^\nu\right)}{\frac{\theta}{\theta-1}} y_t + \frac{\tau\left(\bar{Y} - \eta_{im}\bar{Y}^{1-\nu}\bar{IM}^\nu\right)}{\frac{\theta^2}{\theta-1}} (y_t - \tilde{y}_t)$$

$$- \frac{\tau\eta_{im}\nu\bar{Y}^{1-\nu}\bar{IM}^\nu}{\frac{\theta}{\theta-1}} im_t - \bar{G} g_t = 0$$

$$ex_t - \kappa q_t - \varsigma y_t^* = 0$$

$$q_t - (1-\nu) y_t - \frac{1}{\theta}(y_t - \tilde{y}_t) + (1-\nu) im_t = 0$$

$$\bar{C} c_t - \frac{(1-\eta)}{\eta} \bar{C}^h c_t^h - \bar{C}^e c_t^e = 0$$

$$\bar{CA} ca_t - \bar{EX} ex_t + \bar{Q} q_t + \bar{IM} im_t = 0$$

$$c_t^h - \psi_t + E_t[r_{t+1}] - E_t\left[c_{t+1}^h\right] - E_t[i_{t+1}] = 0$$

$$E_t[r_{t+1}] + E_t[ir_{t+1}] - \psi_t = 0$$

$$E_t[q_{t+1}] - E_t[q_t] + E_t\left[i_{t+1}^*\right] - E_t\left[\pi_{t+1}^*\right] - E_t[i_{t+1}] + E_t[\pi_{t+1}] = 0$$

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