The effects of asymmetric information between borrowers and lenders in an open economy

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Abstract

This paper assesses the effects of asymmetric information between borrowers and lenders in an open economy with access to international capital markets. Information asymmetry and agency costs arise because only borrowers can costlessly observe actual returns from production. Agency costs increase the cost of external finance and lower steady state investment, capital and output. They also affect the business cycle and the central bank's response to shocks. The long-run effects of agency costs are exacerbated in an open economy and their impact is influenced by the degree of access to international capital markets. The results thus highlight the importance of incorporating credit market interactions into open economy macroeconomic models.

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1 Introduction

This paper develops a theoretical model to assess the effects of asymmetric information between borrowers and lenders in an open economy with access to international capital markets. Information asymmetry arises in credit markets because borrowers know more about their investment projects than lenders do. It leads to agency costs when lenders delegate control over resources to borrowers, and borrowers (agents) have an incentive not to perform in the best interest of lenders (principals).

The idea that credit markets can have real economic effects is not new. It has been examined since at least Wicksell's early writings on monetary dynamics (Wicksell, 1906) and Fisher's "debt-deflation theory of great depressions" (Fisher, 1933). More recently, distressed financial and banking systems, e.g. in the United States, the United Kingdom, Scandinavia, Latin America, Japan and other east Asian countries, have rekindled interest in the role of credit markets in economic activity.

Based on Bernanke and Gertler's (1989) seminal contribution, Carlstrom and Fuerst (1997) and Bernanke, Gertler and Gilchrist (1999) develop a closed economy general equilibrium model, in which agency costs increase firms' cost of external finance relative to internal funds.[1] However, imperfect information and the resulting credit market frictions may be more pronounced in small open economies than in large closed economies. Small economies tend to have a large number of small firms, which are more affected by asymmetric information than large businesses, because of economies of scale in acquiring and monitoring information.[2] Moreover, in open economies with access to international capital markets, domestic savings are not constrained to domestic (risky) investments. Furthermore, the cost of borrowing is influenced by movements in the relative price of currencies, i.e. the exchange rate.

[1] Much of the literature to date has focused on the United States, a large semi-closed economy. See also Fuerst (1995) and Fisher (1999).

[2] For instance, Gertler and Gilchrist (1994) find that, following economic downturns, borrowing and output by bank dependent firms, which are typically small, often fall more than borrowing and output by large firms with access to public debt markets.

The model in this paper builds on Carlstrom and Fuerst's (1997) closed economy agency cost model. It is extended to an open economy with a floating exchange rate, foreign trade and access to international capital markets. The model also includes an inflation targeting monetary authority and a government and domestic prices are assumed to converge only gradually to world prices (adjusted for the exchange rate), i.e. prices are sticky.

The paper proceeds as follows. Section 2 develops a theoretical small open economy agency cost model that is calibrated to New Zealand. The long-run and business cycle effects of asymmetric information and agency costs are examined in sections 3 and 4. Section 5 presents some sensitivity analysis and the last section summarizes and concludes.

2 Theoretical model

There are six agents in the economy: households, firms, financial intermediaries, entrepreneurs, a government and a monetary authority. Households and entrepreneurs form a continuum of agents with unit mass. The proportions of households and entrepreneurs are given by $(1-\eta)$ and η.

2.1 Financial intermediaries

Financial intermediaries provide external financing to entrepreneurs. They help overcome an information asymmetry that arises because entrepreneurs must use external finance to produce capital, an input into firms' production, and because their technology is subject to idiosyncratic shocks that only entrepreneurs can costlessly observe. More specifically, 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 capital.[3] Each entrepreneur i produces capital by using their own internal funds or net

[3] The random variable $\omega_t(i)$ is assumed to be lognormally distributed across time and entrepreneurs, i.e. $\ln(\omega_t(i)) \sim N(\tilde{\mu},\ \tilde{\sigma}^2)$, with a mean of unity and a standard deviation of σ.

worth $NW_t(i)$ and by borrowing $(IN_t(i) - NW_t(i))$ consumption goods from financial intermediaries. After new capital is produced loans are repaid in capital goods. The distribution function and density of the technology shock are given by $\Phi(\omega_t(i))$ and $\phi(\omega_t(i))$.

Agency costs arise because lenders can only observe each entrepreneur's technology shock $\omega_t(i)$ 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 the true value of their production shock $\omega_t(i)$. The optimal contract is structured so that entrepreneur i always truthfully reports the value of $\omega_t(i)$. The contract is risky debt and characterized by the size of entrepreneur i's project, $IN_t(i)$, and a critical $\omega_t(i)$ that triggers bankruptcy, denoted by $\varpi_t(i)$. If the realization 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, $f(\varpi_t(i))$ and $g(\varpi_t(i))$, are defined. They are the fractions of the expected net capital output received by the entrepreneur and lender. Because of expected bankruptcy and monitoring costs the fractions do not sum to one , i.e. $f(\varpi_t(i)) + g(\varpi_t(i)) = 1 - \alpha\Phi(\varpi_t(i))$, where α denotes the monitoring cost and $\Phi(\varpi_t(i))$ is the probability of default and monitoring occurring.[4] The expected net capital output from project $IN_t(i)$ received by the entrepreneur and lender is given by $f(\varpi_t(i))\hat{\Psi}_t IN_t(i)$ and $g(\varpi_t(i))\hat{\Psi}_t IN_t(i)$, where $\hat{\Psi}_t$ is the economy wide real price of capital in terms of consumption goods.

Instead of lending to entrepreneurs financial intermediaries can hold risk-free foreign bonds. Access to international capital markets thus increases the opportunity cost of lending to risky

[4] 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 ω in excess of ϖ and $g(\varpi)$ integrates over 0 to ϖ.

entrepreneurs, who may default on their debt, and increases the rate of return lenders demand for the use of their funds. Risk-free foreign bonds earn a real rate of return of $(1+I_t^*)\,Q_t/\,(1+\Pi_t^*)$, where I_t^* is the nominal interest rate paid on foreign bonds, Π_t^* is the foreign inflation rate and Q_t denotes the real exchange rate.[5]

The optimal contract is given by the project size $IN_t\,(i)$ and the critical technology shock $\varpi_t\,(i)$ that triggers bankruptcy. It maximizes entrepreneur i's net capital output, $f\,(\varpi_t\,(i))\,\hat{\Psi}_t IN_t\,(i)$, subject to the financial intermediary being indifferent between lending to the entrepreneur, $g\,(\varpi_t\,(i))\,\hat{\Psi}_t IN_t\,(i)$, and loaning the funds, $(IN_t\,(i)-NW_t\,(i))$, internationally at $(1+I_t^*)\,Q_t/\,(1+\Pi_t^*)$, i.e.

$$\max f\,(\varpi_t\,(i))\,\hat{\Psi}_t IN_t\,(i) \tag{1}$$

subject to[6]

$$g\,(\varpi_t\,(i))\,\hat{\Psi}_t IN_t\,(i) \geq \frac{(1+I_t^*)Q_t(IN_t(i)-NW_t(i))}{1+\Pi_t^*} \tag{2}$$

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

$$\frac{f(\varpi_t(i))}{f'(\varpi_t(i))} = \frac{g(\varpi_t(i))\hat{\Psi}_t - \frac{(1+I_t^*)Q_t}{1+\Pi_t^*}}{g'(\varpi_t(i))\hat{\Psi}_t} \tag{3}$$

which can be re-written as

$$\hat{\Psi}_t \left(1-\alpha\Phi\,(\varpi_t\,(i)) + \frac{\alpha\phi(\varpi_t(i))f(\varpi_t(i))}{f'(\varpi_t(i))}\right) = \frac{(1+I_t^*)Q_t}{1+\Pi_t^*} \tag{4}$$

and

$$IN_t\,(i) = \frac{\frac{(1+I_t^*)Q_t}{1+\Pi_t^*}NW_t(i)}{\frac{(1+I_t^*)Q_t}{1+\Pi_t^*} - g(\varpi_t(i))\hat{\Psi}_t} \tag{5}$$

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[5] The exchange rate is measured as the price of foreign currency in units of domestic currency, i.e. an increase in Q_t indicates a real depreciation of the domestic currency.

[6] At an optimum equation (2) holds as an equality.

Equation (4) determines the critical technology shock that triggers bankruptcy, $\varpi_t(i)$. It is independent of i but a function of the distribution of the stochastic technology shock, $\omega_t(i)$, the monitoring cost, α, the price of capital, $\hat{\Psi}_t$, the real exchange rate, Q_t, and the foreign real interest rate, $(1+I_t^*)/(1+\Pi_t^*)$. The result that the optimal contract is independent of i implies that all entrepreneurs receive the same basic terms on their debt contract.[7] Contracts only differ in terms of size. Entrepreneurs with larger net worth receive a proportionately larger loan (equation 5). Moreover, the size of loans that financial intermediaries are willing to provide to entrepreneurs is determined by the opportunity cost of not lending internationally, i.e. $(1+I_t^*)\,Q_t/(1+\Pi_t^*)$.

2.2 Households

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

$$E_t \sum_{k=0}^{\infty} \beta^k \left\{ \ln\left(C_{t+k}^h\right) + \gamma\left(1 - N_{t+k}\right) \right\} \tag{6}$$

where $\gamma > 0$ is a parameter, $\beta \in (0,1)$ denotes the household's discount factor and E_t is a conditional expectations operator with respect to information available at time t. 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.[8] 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' time endowment is normalized to one. Their labour supply is given by N_t and $(1-N_t)$ is leisure.

Households earn income from supplying labour, N_t, at wage rate W_t^h and by renting capital,

[7] The result follows from the assumption of linear monitoring costs and investment technology. Variables specific to i can henceforth be interpreted as averages.

[8] The entrepreneur's and government's consumption indexes (discussed below) are given accordingly.

K^h_{t-1}, which they accumulated last period, to firms at rate R_t. Households also receive dividend payments, Ω_t, from firms and earn income from holding domestic bonds issued by financial intermediaries, B^h_{t-1}, and foreign bonds, B^{h*}_{t-1}. Domestic bonds, B^h_{t-1}, earn a nominal return (in terms of domestic currency) of I_t. As in Carlstrom and Fuerst (2000) households also hold demand deposits, D_{t-1}, to purchase consumption and capital goods. Demand deposits do not earn any interest. 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 τ. The typical household's budget constraint is thus given by

$$\begin{aligned} &(1-\tau)\,W^h_t N_t + ((1-\delta)\,\Psi_t + (1-\tau)\,R_t)\,K^h_{t-1} + (1+I_t)\,B^h_{t-1} \\ &+ (1+I^*_t)\,S_t B^{h*}_{t-1} + \Omega_t + D_{t-1} - P_t C^h_t - B^h_t - S_t B^{h*}_t - D_t - \Psi_t K^h_t = 0 \end{aligned} \tag{7}$$

where S_t denotes the nominal exchange rate and δ is the depreciation rate of capital.

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

$$P_t C^h_t + \Psi_t K^h_t - (1-\delta)\,\Psi_t K^h_{t-1} \leq D_{t-1} \tag{8}$$

It holds as an equality at an optimum if $I_t > 0$. Using equation (8), the household's budget constraint can then be re-written in real terms as

$$\begin{aligned} &(1-\tau)\,\hat{W}^h_t N_t + (1-\tau)\,\hat{R}_t K^h_{t-1} + \tfrac{(1+I_t)\hat{B}^h_{t-1}}{1+\Pi_t} + \tfrac{(1+I^*_t)Q_t\hat{B}^{h*}_{t-1}}{1+\Pi^*_t} + \hat{\Omega}_t - \hat{B}^h_t \\ &-Q_t\hat{B}^{h*}_t - (1+\Pi_{t+1})\left(C^h_{t+1} + \hat{\Psi}_{t+1}K^h_{t+1} - (1-\delta)\,\hat{\Psi}_{t+1}K^h_t\right) = 0 \end{aligned} \tag{9}$$

The real wage and rental rate of capital are given by $\hat{W}^h_t$ and $\hat{R}_t$, and $\hat{B}^h_t$, $\hat{B}^{h*}_t$ and $\hat{\Omega}_t$ are the household's domestic and foreign bond holdings and dividend payments from firms in real terms.

The real exchange rate is given by $Q_t \equiv S_t P_t^*/P_t$, and Π_t is the domestic inflation rate with $\Pi_t = P_t/P_{t-1} - 1$. The foreign inflation rate, Π_t^*, is given by $\Pi_t^* = P_t^*/P_{t-1}^* - 1$, where P_t^* is the aggregate foreign price level.

The household's optimization 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 maximize lifetime utility (equation 6) subject to equation (9).[9] Households' first-order conditions are given by

$$\frac{1}{\gamma C_t^h} - \frac{1+I_t}{(1-\tau)\hat{W}_t^h} = 0 \tag{10}$$

$$\frac{\hat{\Psi}_t}{C_t^h} - E_t\left[\frac{\beta\left((1-\delta)\hat{\Psi}_{t+1} + \frac{(1-\tau)\hat{R}_{t+1}}{1+I_{t+1}}\right)}{C_{t+1}^h}\right] = 0 \tag{11}$$

and

$$E_t\left[\frac{Q_{t+1}}{Q_t}\frac{1+I_{t+1}^*}{1+\Pi_{t+1}^*} - \frac{1+I_{t+1}}{1+\Pi_{t+1}}\right] = 0 \tag{12}$$

Equation (10) indicates that 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. 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. Equation (11) implies that 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. Equation (12) indicates that the real rates of return from holding domestic and foreign bonds are equal and households are indifferent between holding domestic or foreign bonds.

[9] Dividends are paid at the end of each period and do not affect households' optimization problem.

2.3 Firms

Firms are monopolistic competitors and specialize 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

$$\begin{aligned} Y_t(j) = {} & [(\eta_l \left(Z_t L_t^h(j)\right)^{\nu} + \eta_k \left(K_{t-1}(j)\right)^{\nu} \\ & + \eta_{im} \left(IM_t(j)\right)^{\nu} + (1 - \eta_l - \eta_k - \eta_{im}) \left(L_t^e(j)\right)^{\nu}]^{\frac{1}{\nu}} \end{aligned} \tag{13}$$

where η_l, η_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 $1/(1-\nu)$.

Each firm sells its output of consumption good, $Y_t(j)$, to domestic households, entrepreneurs and the government. Firms also export to the rest of the world.[10] Aggregate exports, EX_t, are a function of the real exchange rate, Q_t, and foreign demand for the domestic country's output, Y_t^*, and are given by

$$EX_t = (Q_t)^{\kappa} (Y_t^*)^{\varsigma} \tag{14}$$

where κ, $\varsigma > 0$ are the price and foreign demand elasticities of exports.[11]

[10] Each firm treats the price in domestic currency, $P_t(j)$, of the 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. Firms may not price discriminate and the price of good j sold to foreign consumers (denominated in foreign currency) is given by $P_t(j)/S_t$. The demand functions for good j are given by $C_t^h(j) = (P_t(j)/P_t)^{-\theta} C_t^h$, $C_t^e(j) = (P_t(j)/P_t)^{-\theta} C_t^e$, $G_t(j) = (P_t(j)/P_t)^{-\theta} G_t$ and $EX_t(j) = (P_t(j)/P_t)^{-\theta} EX_t$. $C_t^h(j)$, $C_t^e(j)$, $G_t(j)$ and $EX_t(j)$ are the quantity of good j demanded by a typical household and entrepreneur, the government and a typical foreign consumer. C_t^h, C_t^e, G_t and EX_t denote total consumption by households and entrepreneurs, government consumption and aggregate exports.

[11] The domestic economy's exports are assumed to form an insignificant proportion of foreigners' demand and have

Each firm chooses $\left\{P_t(j),\ L_t^h(j),\ L_t^e(j),\ IM_t(j),\ K_{t-1}(j)\right\}$ to maximize profits subject to its production function (13) and demand function, $Y_t(j) = \left(P_t(j)/P_t\right)^{-\theta} Y_t$. Profits, $\Theta_t(j)$, are given by

$$\begin{aligned} \Theta_t(j) &= \left[P_t(j)\, Y_t(j) - W_t^h L_t^h(j) - W_t^e L_t^e(j) - R_t K_{t-1}(j) - S_t P_t^* IM_t(j)\right] \\ &= \left[P_t(j) - P_t MC_t\right] \left(\tfrac{P_t(j)}{P_t}\right)^{-\theta} Y_t \end{aligned} \tag{15}$$

where W_t^e denotes the nominal wage rate for entrepreneurial labour and MC_t is the real marginal cost. Firm j's first-order conditions are given by

$$P_t(j) = \tfrac{\theta}{\theta-1} P_t MC_t \tag{16}$$

$$\frac{W_t^h}{P_t(j)} = \frac{\eta_l (Z_t)^{\nu} \left(\frac{Y_t(j)}{L_t^h(j)}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{17}$$

$$\frac{W_t^e}{P_t(j)} = \frac{(1-\eta_l-\eta_k-\eta_{im}) \left(\frac{Y_t(j)}{L_t^e(j)}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{18}$$

$$\frac{R_t}{P_t(j)} = \frac{\eta_k \left(\frac{Y_t(j)}{K_{t-1}(j)}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{19}$$

and

$$\frac{S_t P_t^*}{P_t(j)} = \frac{\eta_{im} \left(\frac{Y_t(j)}{IM_t(j)}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{20}$$

In a symmetric equilibrium, all firms charge the same price, produce the same output, employ the same labour and use the same capital and commodity inputs. Equations (16) to (20) can then be re-written as

$$MC_t = \frac{1}{\frac{\theta}{\theta-1}} \tag{21}$$

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a negligible weight in the rest of the world's price index.

$$\hat{W}_t^h = \frac{\eta_l (Z_t)^\nu \left(\frac{Y_t}{L_t^h}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{22}$$

$$\hat{W}_t^e = \frac{(1-\eta_l-\eta_k-\eta_{im})\left(\frac{Y_t}{L_t^e}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{23}$$

$$\hat{R}_t = \frac{\eta_k \left(\frac{Y_t}{K_{t-1}}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{24}$$

and

$$Q_t = \frac{\eta_{im} \left(\frac{Y_t}{IM_t}\right)^{1-\nu}}{\frac{\theta}{\theta-1}} \tag{25}$$

where $\hat{W}_t^e$ denotes the real wage rate for entrepreneurial labour. The first-order conditions (22) to (25) 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 ξ_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.

2.4 Entrepreneurs

Entrepreneurs are infinitely lived and produce the capital that firms use in the production of consumption goods. As discussed in section 2.1, each entrepreneur has access to a stochastic technology, ω_t, that transforms an input of IN_t consumption goods into $\omega_t IN_t$ units of capital. To finance the production of the capital good, entrepreneurs use their own net worth and obtain external financing from financial intermediaries. Entrepreneurs' net worth consists of their after-tax wage earnings and the market value of their capital stock. The production of capital goods uses consumption goods and entrepreneurs sell their accumulated capital stock to households via financial intermediaries for consumption goods before production commences.

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

$$NW_t = (1-\tau)\,\hat{W}_t^e + \Big((1-\delta)\,\hat{\Psi}_t + (1-\tau)\,\hat{R}_t\Big)\,K_{t-1}^e \tag{26}$$

where entrepreneurial labour supply is equal to unity and K_{t-1}^e is the entrepreneur's capital stock. The assumption of entrepreneurial labour income ensures that entrepreneurs always have a nonzero level of net worth.

After production of the capital good commences the idiosyncratic technology shock, ω_t, is realized. Entrepreneurs who are still solvent after the shock occurs repay their loans and make their consumption decisions. The typical entrepreneur's utility function is given by

$$E_t \sum_{k=0}^{\infty} (\zeta\beta)^k\, C_{t+k}^e \tag{27}$$

where C_t^e 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. With no external financing, agency costs disappear. The additional discount factor avoids this outcome. The gross expected return to internal funds is given by

$$1 + IR_t = \tfrac{f(\varpi_t)\hat{\Psi}_t}{1-g(\varpi_t)\hat{\Psi}_t} \tag{28}$$

where $f(\varpi_t)\,\hat{\Psi}_t$ is the expected share of net capital output received by the entrepreneur and $g(\varpi_t)\,\hat{\Psi}_t$ is the expected share received by the lender.

The typical entrepreneur's budget constraint, after loan repayment in the form of newly created capital, is given by

$$\left((1-\tau)\hat{W}_t^e + \left((1-\delta)\hat{\Psi}_t + (1-\tau)\hat{R}_t\right)K_{t-1}^e\right)\frac{f(\varpi_t)\hat{\Psi}_t}{1-g(\varpi_t)\hat{\Psi}_t} - C_t^e - \hat{\Psi}_t K_t^e = 0 \tag{29}$$

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 (29) states that the entrepreneur's net worth, $(1-\tau)\hat{W}_t^e + ((1-\delta)\hat{\Psi}_t + (1-\tau)\hat{R}_t)K_{t-1}^e$, earns an expected return to internal funds of $f(\varpi_t)\hat{\Psi}_t / \left(1-g(\varpi_t)\hat{\Psi}_t\right)$. The entrepreneur then sells a proportion of this newly created capital to households via financial intermediaries to purchase consumption goods, C_t^e. The capital left after consumption is given by K_t^e.

The entrepreneur's optimization problem consists of choosing $\{C_t^e,\ K_t^e\}$ for all $t \in [0,\infty)$ to maximize lifetime utility (equation 27) subject to equation (29). The entrepreneur's first-order condition is given by

$$\hat{\Psi}_t = E_t\left[\frac{\zeta\beta\left((1-\delta)\hat{\Psi}_{t+1} + (1-\tau)\hat{R}_{t+1}\right)f(\varpi_{t+1})\hat{\Psi}_{t+1}}{1-g(\varpi_{t+1})\hat{\Psi}_{t+1}}\right] \tag{30}$$

where the gross expected return on internal funds, $f(\varpi_{t+1})\hat{\Psi}_{t+1} / \left(1-g(\varpi_{t+1})\hat{\Psi}_{t+1}\right)$, is greater than one. It is this additional return that encourages entrepreneurs to accumulate capital even though they discount the future more than households. To avoid self-financing, in the calibration ζ is set to offset the steady state internal return, i.e. $\zeta f(\bar{\varpi})\bar{\Psi} / \left(1-g(\bar{\varpi})\bar{\Psi}\right) = 1.$[12]

2.5 Government

The government's budget constraint is given by

$$\tau\left(\hat{W}_t^h L_t^h + \hat{W}_t^e L_t^e + \hat{R}_t K_{t-1}\right) - G_t = 0 \tag{31}$$

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

The government collects taxes on households' and entrepreneurs' wage and rental incomes, $\tau\left(\hat{W}_t^h L_t^h + \hat{W}_t^e L_t^e + \hat{R}_t K_{t-1}\right)$. 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, i.e. there is no debt financing.

2.6 Monetary authority

The monetary authority has an explicit consumer price inflation target, Π^T. To maintain this target the central bank adjusts the nominal rate of interest paid on domestic bonds. Its reaction function is given by a Taylor rule (Taylor, 1993), i.e. it depends on deviations of inflation from target and deviations of output from long-run, full capacity output. Moreover, it is a function of the past interest rate.[13] The interest reaction is constrained to be linear in the logs of the relevant arguments and given by

$$\ln\left(\frac{1+I_t}{1+\bar{I}}\right) = \mu_1 \ln\left(\frac{1+\Pi_t}{1+\Pi^T}\right) + \mu_2 \ln\left(\frac{Y_t}{\bar{Y}}\right) + \mu_3 \ln\left(\frac{1+I_{t-1}}{1+\bar{I}}\right) \tag{32}$$

where μ_1, $\mu_2, \mu_3 > 0$ are parameters and $\bar{I}$ and $\bar{Y}$ denote the steady state interest rate and long-run, full capacity output.

2.7 Equilibrium conditions

There are four domestic markets in the economy: two labour markets, a consumption goods market and a capital goods market. The clearing conditions are given by

$$L_t^h = (1-\eta)\, N_t \tag{33}$$

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

$$L_t^e = \eta \tag{34}$$

$$Y_t = (1-\eta) C_t^h + \eta C_t^e + G_t + EX_t + \eta IN_t \tag{35}$$

and

$$K_t = (1-\delta) K_{t-1} + \eta IN_t (1 - \alpha \Phi(\varpi_t)) \tag{36}$$

where η is the ratio of entrepreneurs to households and entrepreneurial labour supply is equal to unity.

For simplicity, all household bonds are assumed to be in foreign securities. Foreign bond holdings are determined at the end of each period from the foreign sector clearing condition. They do not affect decisions and are hence disregarded.

The current account balance is given by

$$CA_t = EX_t - Q_t IM_t \tag{37}$$

and the real exchange rate evolves according to

$$E_t\left[\frac{Q_{t+1}}{Q_t}\right] = E_t\left[\frac{\frac{S_{t+1}}{S_t}\frac{P_{t+1}^*}{P_t^*}}{\frac{P_{t+1}}{P_t}}\right] \tag{38}$$

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.

3 Long-run effects of agency costs

To assess the long-run effects of asymmetric information and agency costs, the theoretical model is solved for a steady state with and without agency costs and the two steady states are compared. To solve for the steady states requires parameterizing the model. Values are chosen so that the steady state of the agency cost model is broadly consistent with New Zealand data and/or assumptions made in the literature. A period in the model corresponds to one quarter. Appendix A contains the details of the parameterization and the equations solving for the agency cost model. The equations for the model without agency costs are obtained by setting the variables that give rise to agency costs (discussed next) to zero.

Agency costs arise because entrepreneurs' production technology is stochastic and because entrepreneurs must use external financing. Agency costs disappear when entrepreneurs' production process is certain. Without idiosyncratic technology shocks entrepreneurs no longer become bankrupt and default on their debt. Moreover, with a certain production process there are no ex post information asymmetries about the return to investment projects. Financial intermediaries' monitoring costs become zero and entrepreneurs can borrow directly from households. In fact, entrepreneurs obtain all external financing from households and do not need to accumulate net worth. As a result, entrepreneurs' capital is zero. Entrepreneurs' wage earnings and consumption are also set to zero for simplicity. Moreover, the external finance premium is zero; that is, the real price of capital is equal to unity.

The steady states of the model with and without agency costs are summarized in Table 1. Columns (1) and (2) report the steady state values for the variables in the agency cost model and the model without agency costs, while column (3) shows the percent (percentage point) differences between the two models.

The results in Table 1 show that asymmetric information and agency costs have long-run real effects. They raise the cost of external finance and the price of capital. The effects of agency costs are further exacerbated in the open economy. This is because the price of capital in the open economy agency cost model is higher than in Carlstrom and Fuerst's (1997) closed economy model

Table 1: Numerical steady state

		Agency cost model (1)	No agency costs (2)	Difference (3)
$\bar{K}$	capital	26.068	27.151	4.2 %
$\bar{K}^e$	entrepreneurial capital	0.196	n/a	n/a
$\bar{NW}$	entrepreneurial net worth	0.206	n/a	n/a
$\bar{IN}$	investment	0.538	0.559	3.9 %
$\bar{C}^h$	household consumption	0.322	0.327	1.5 %
$\bar{C}^e$	entrepreneurial consumption	0.020	n/a	n/a
$\bar{C}$	aggregate consumption	2.918	2.940	0.8 %
$\bar{G}$	government consumption	0.544	0.551	1.3 %
$\bar{EX}$	exports	0.494	0.501	1.3 %
$\bar{Y}$	output	4.495	4.552	1.3 %
$\bar{L}^h$	household labour	2.700	2.700	0.0 %
$\bar{IM}$	imports	0.544	0.551	1.3 %
$\bar{CA}$	current account	−0.049	−0.050	−1.3 %
$\bar{\Psi}$	price of capital	1.034	1.000	−3.4 %
$\bar{\Psi}-1$	cost of external finance	3.4 %	0.0 %	−3.4 p.p.
$\bar{R}$	rental rate of capital	5.3 %	1.2 %	−4.1 p.p.
$\bar{IR}$	return to internal funds	8.3 %	n/a	n/a
$\bar{C}/\bar{Y}$	aggregate consumption to output	64.9 %	64.6 %	−0.3 p.p.
$\bar{G}/\bar{Y}$	government consumption to output	12.1 %	12.1 %	0.0 p.p.
$\bar{IN}/\bar{Y}$	investment to output	12.0 %	12.3 %	0.3 p.p.
$\bar{EX}/\bar{Y}$	exports to output	11.0 %	11.0 %	0.0 p.p.
$\bar{IM}/\bar{Y}$	imports to output	12.1 %	12.1 %	0.0 p.p.
$\bar{CA}/\bar{Y}$	current account to output	−1.1 %	−1.1 %	0.0 p.p.

Note: $\bar{K}$, $\bar{K}^e$, $\bar{NW}$, $\bar{IN}$, $\bar{C}^h$, $\bar{C}^e$, $\bar{C}$, $\bar{G}$, $\bar{EX}$, $\bar{Y}$, $\bar{L}^h$ and $\bar{IM}$ denote steady state averages. All variables are reported at quarterly rates. Differences between the model without agency costs and the agency cost model in column (3) are in percent (%) or percentage points (p.p.).

(1.034, compared to 1.024). The cost of external finance and the price of capital are higher because access to international capital markets increases the opportunity cost of lending to risky borrowers. This raises the rate of return lenders demand for the use of their funds.

Without agency costs the price and rental rate of capital fall, increasing steady state investment and capital by about 3.9 percent and 4.2 percent, while output rises by 1.3 percent. Commodity imports, which are an input into production, increase with the rise in output and steady state exports, which are a fixed proportion of output, are also higher. The increase in output raises households' wage rate.[14] Households' rental income also increases because of a larger capital stock. Higher incomes raise households' consumption and government consumption rises due to increased tax revenue.

4 Business cycle effects

The effects of asymmetric information and agency costs on the business cycle are examined next. This requires taking a log-linear approximation around the steady state of the agency cost model and the model without agency costs. The two log-linearized models are then subjected to a range of exogenous shocks and the adjustment paths of the agency cost model back to steady state are compared to those of the model without agency costs.[15] Appendix B gives the log-linearized equations of the agency cost model. It also specifies the inflation process and full capacity, flexible price output, which enter the central bank's reaction function, and the shock processes. The equations for the model without agency costs are obtained by setting the log-deviations of variables giving rise to agency costs (discussed in the previous section) to zero.

To illustrate the effects of agency costs on the business cycle the adjustment paths to a supply shock and a demand shock are presented: to aggregate productivity and foreign demand. The impulse responses of the variables in the models with and without agency costs are plotted in Figures 1 and 2 as percent deviations from steady state. The solid line shows the responses in the agency cost model and the dotted line is the economy without agency costs. All variables eventually return to steady state.

[14] Household labour is assumed constant.

[15] The log-linearized models (with and without agency costs) are solved with the method of undetermined coefficients. Uhlig's (1999) procedures for MATLAB are used.

4.1 Productivity shock

The impulse responses of the variables in the agency cost model and the model without agency costs to a positive temporary productivity shock are plotted in Figure 1. The results confirm the closed economy finding that agency costs impact on the business cycle. In fact, the effects are reinforced in the open economy. This is because the cost of external finance is further influenced by the exchange rate.

Following a positive shock to productivity output rises more gradually and by less in the agency cost model compared to the model without agency costs. This is because in the agency cost model the supply shock increases the cost of external finance to produce capital. Also adding to the higher cost of external finance is a real exchange rate appreciation following the positive productivity shock. The appreciation of the domestic currency increases the relative return to foreign assets and reduces (domestic and foreign) lenders' willingness to provide funds to entrepreneurs. The higher cost of external finance increases the probability of default and monitoring costs and lowers investment and output. Moreover, entrepreneurs' net worth only increases with a lag because entrepreneurs' capital is initially fixed.[16] The delayed increase in net worth causes a hump-shaped response in investment and output. The increase in imports is also hump-shaped and household labour increases after an initial decline following the labour-augmenting productivity shock.

Without agency costs investment and output rise instantaneously and then slowly return to steady state as productivity starts declining. The increase in investment and output is larger than in the agency cost model as the productivity shock does not affect the cost of external finance. Without agency costs the external finance premium is zero. The adjustment of household labour and imports is also instantaneous.[17]

[16] The increase in the cost of external finance, the 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.

[17] Government consumption in both models mainly follows the response of output.

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

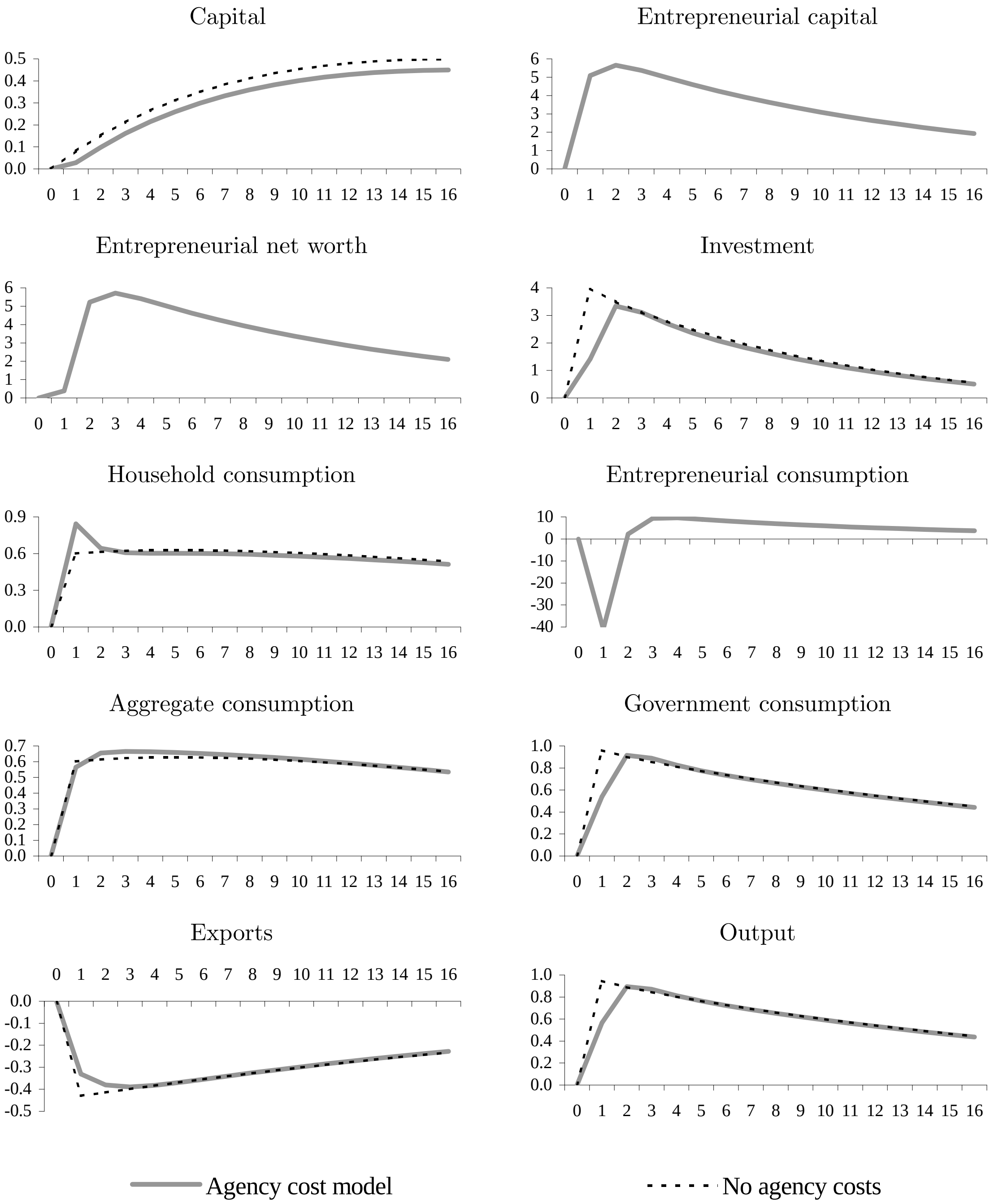
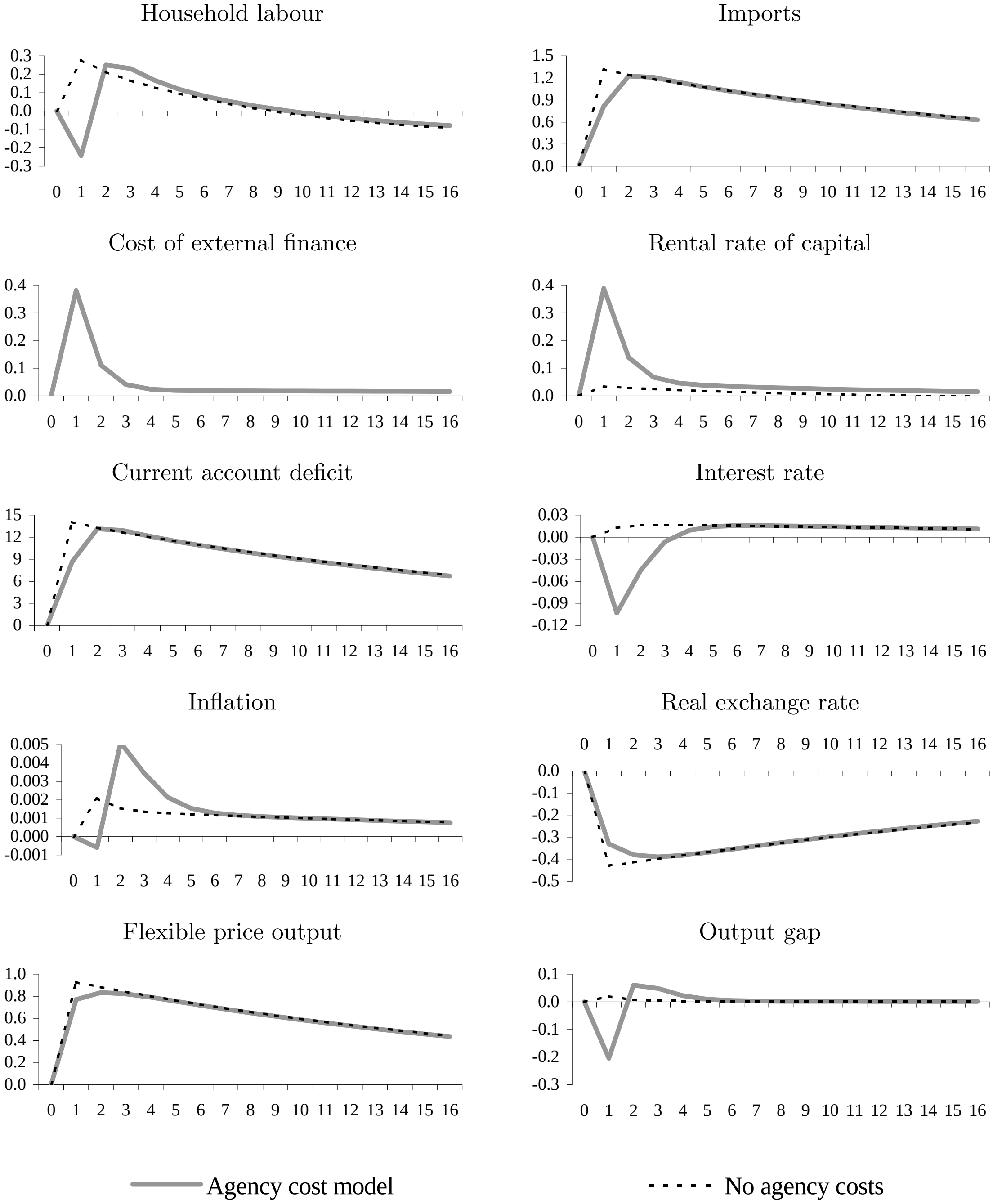


Figure 1 continued



In both models, the real exchange rate appreciates following the positive productivity shock, leading to an increase in the price of exports and a decline in foreign demand and exports. The real appreciation also lowers the cost of imports. But in the agency cost model imports rise and exports fall by less than in the model without agency costs, leading to a smaller increase in the current account deficit. This is because the real exchange rate appreciates by less because the presence of agency costs affects the central bank's response to the shock.

In the agency cost model the monetary authority accommodates the positive supply shock and the nominal interest rate falls. The positive supply shock leads to a negative output gap, downward pressure on inflation and a decline in the interest rate. The negative output gap arises because full capacity, flexible price output increases faster than actual output. This is because actual output adjusts more slowly due to the hump-shaped response. Eventually, the negative output gap is followed by a small positive gap and an increase in inflation, and the central bank raises the interest rate.

In contrast, without agency costs the central bank does not initially ease monetary policy. This is because actual output adjusts instantaneously and increases faster than full capacity, flexible price output, leading to a small positive output gap. The positive output gap puts upward pressure on inflation. The nominal interest rate increases and the tightening in monetary policy leads to a smaller rise in inflation and a larger real exchange rate appreciation.

4.2 Foreign demand shock

The impulse responses of the agency cost model and the model without agency costs to a foreign demand shock are plotted in Figure 2. In both models, a positive temporary foreign demand shock increases exports and output. This leads to inflationary pressures, a tightening in monetary policy and a real appreciation of the domestic currency. In both models, to meet increased foreign demand investment falls. Aggregate consumption also declines after an initial rise. But the presence of agency costs dampens the effects on output. As in the case of the productivity shock, output and employment rise more gradually and by less in the agency cost model compared to the model without agency costs. This is because the real appreciation of the exchange rate reduces lenders' willingness to provide funds to entrepreneurs and increases the cost of external finance. The higher cost of external finance raises the probability of default and monitoring costs and produces a larger decline in investment and a smaller rise in output in the agency cost model compared to the model without agency costs. Moreover, entrepreneurs' net worth only increases with a lag because entrepreneurs' capital is initially fixed, causing a delayed increase in net worth and a hump-shaped response in output. The increase in imports is also hump-shaped and household labour increases after an initial small decline.

Without agency costs output rises instantaneously and the increase is larger than in the agency cost model. This is because the foreign demand shock and real exchange rate appreciation do not affect the cost of external finance and price of capital. The adjustment of household labour and imports is also instantaneous.

In both models, the real appreciation of the domestic currency lowers the cost of imports. The decline in the cost of imports leads to a substitution from domestic factors of production (labour and capital) to foreign factors (imports).[18] The real appreciation also leads to an increase in full capacity, flexible price output. Full capacity output increases by less in the agency cost model because of a larger increase in the rental rate of capital. But in both models, the rise in full capacity, flexible price output is insufficient to meet increased foreign demand, leading to the positive output gap and inflationary pressures. Moreover, in both models, following the positive foreign demand shock imports increase by less than exports and the current account deficit falls.

[18] Household labour increases by more in the model without agency costs because of higher output.

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

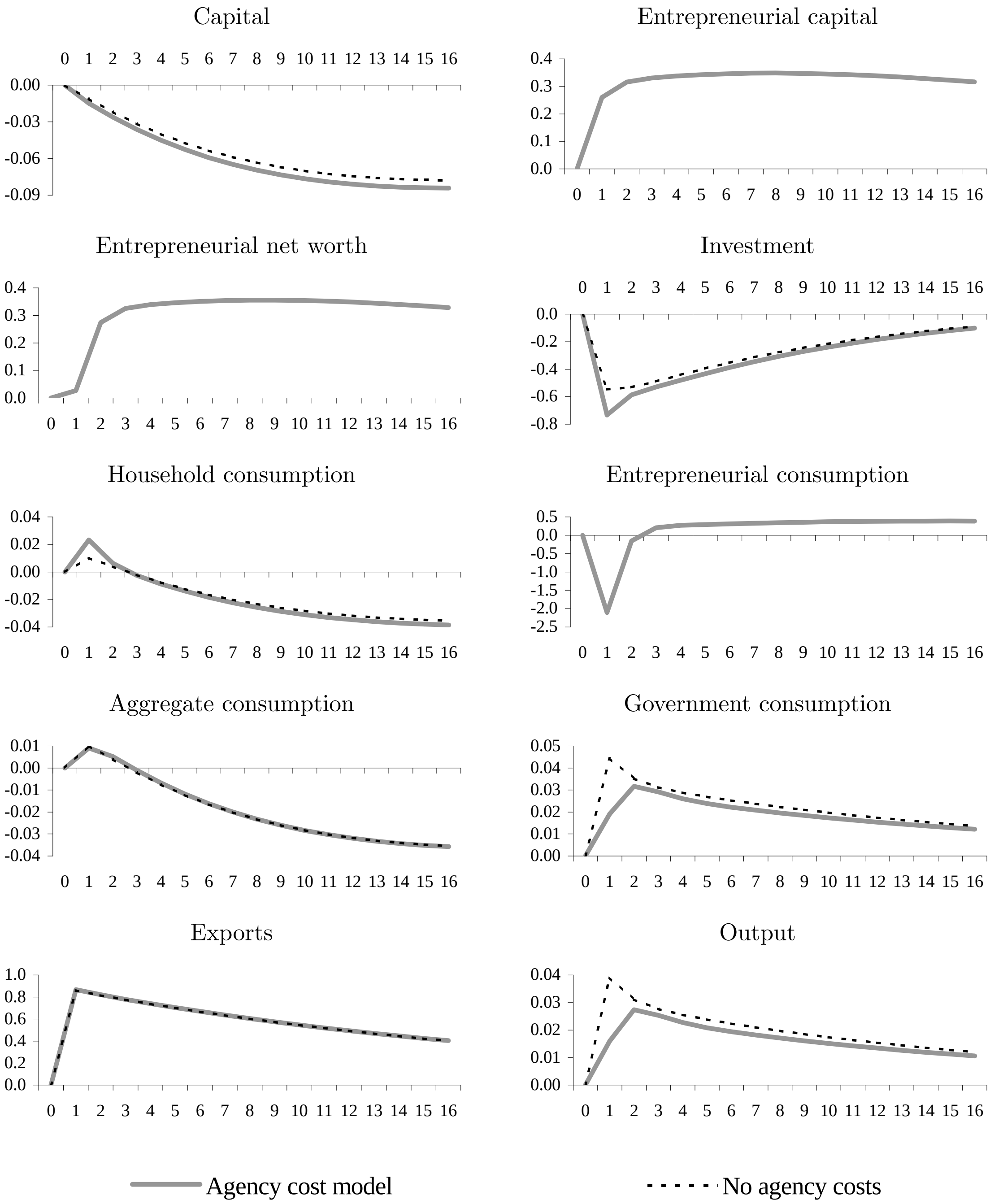
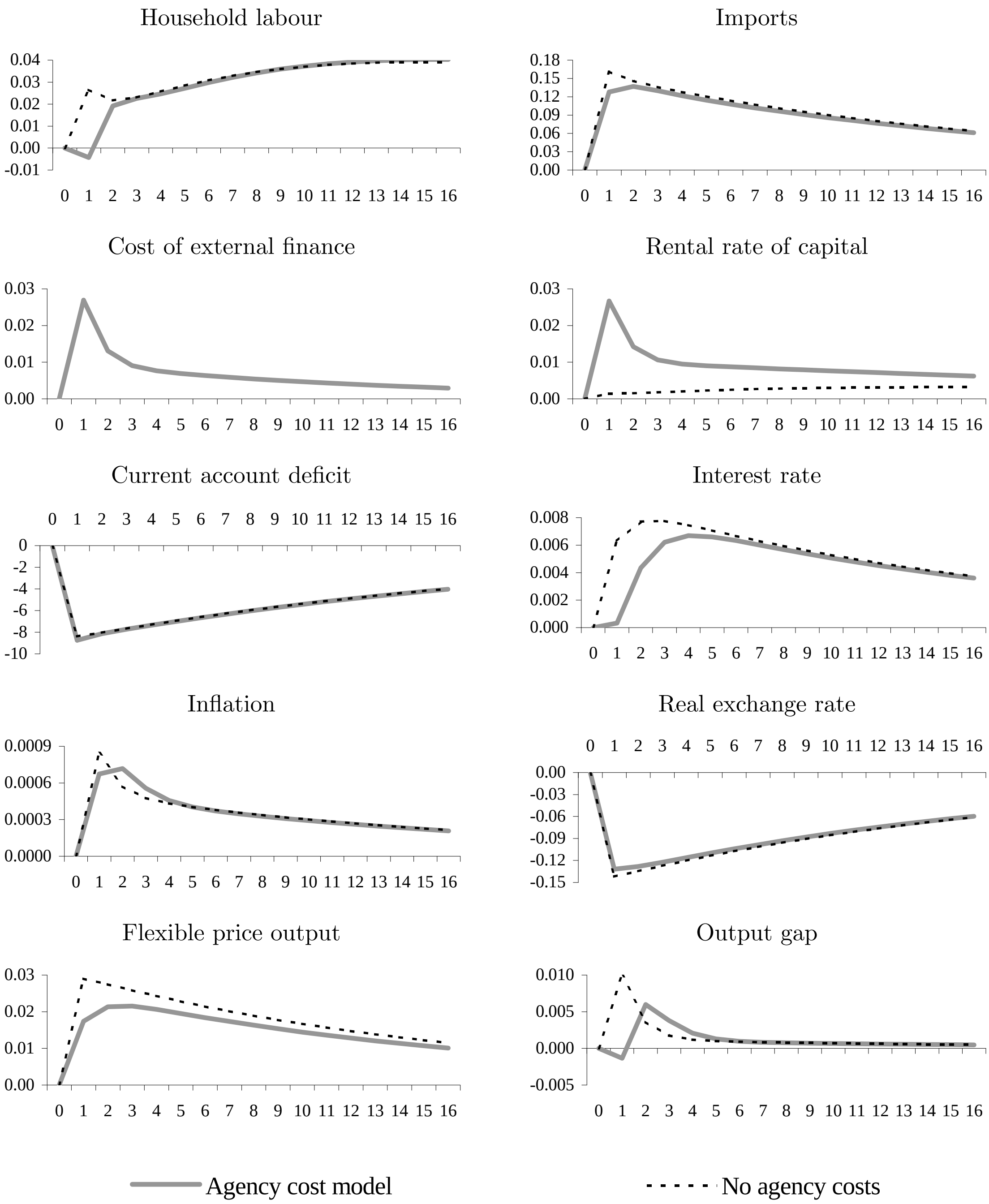


Figure 2 continued



5 Sensitivity analysis

This section presents some sensitivity analysis.[19] The focus is on the foreign sector. Two cases are considered. First, the overall size of foreign trade is reduced. This is achieved by lowering the coefficient on commodity imports in firms' production function and by reducing the steady state ratio of exports to output. Second, it is assumed that financial intermediaries no longer can lend internationally. Both scenarios change the steady state and the dynamic model. The results show that the finding of important agency cost effects is robust to the different specifications of the model. But the impact of agency costs and the cost of external finance is altered with reduced access to international capital markets.

5.1 Lower imports and exports

To reduce the overall size of foreign trade 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. Lowering the import share in firms' production function and the proportion of output that is exported changes the steady state. But the differences between the model without agency costs and the agency cost model are similar to baseline and so the result of long-run real effects of agency costs continues to hold.

In the dynamic model, the results show how shocks originating from the foreign sector have less impact on the domestic economy with a smaller foreign sector. Deviations from steady state are much smaller following a foreign demand shock. The finding of business cycle effects of agency costs however remains unchanged. Agency costs dampen output fluctuations following a shock to the economy. Output rises (falls) more gradually and by less in the agency cost model compared to the model without agency costs following a positive (negative) supply or demand shock.

[19] The results and supporting figures are not presented but available on request.

5.2 Reduced access to international capital markets

To reduce access to international capital markets, it is assumed that financial intermediaries no longer can hold risk-free foreign bonds. The assumption that financial intermediaries can only lend to entrepreneurs lowers the cost of external finance. This is because the cost of external finance no longer includes the opportunity cost of not lending internationally. The reduction in the cost of external finance leads to a higher long-run level of steady state capital, investment, consumption and output. But agency costs still have long-run real effects.

In the dynamic model, the main impact of reduced capital mobility is on the adjustment of the cost of external finance and the rental rate of capital to a demand shock. When financial intermediaries can only lend to entrepreneurs the cost of external finance is no longer affected by exchange rate movements. As a result, the real exchange rate appreciation following the positive demand shock no longer raises the cost of external finance. In fact, the cost of external financing falls as the positive demand shock leads to a reduction in investment to meet increased foreign demand. The decline in the cost of external finance produces a smaller fall in investment and higher output in the agency cost model compared to the model without agency costs. Without capital mobility the presence of agency costs thus magnifies, rather than dampens, the effects on output following a demand shock. The results show that the impact of agency costs and the cost of external finance is influenced by the degree of international capital mobility.

For the productivity shock, the reduction in capital mobility lessens the effects of agency costs. This is because without access to international capital markets the exchange rate no longer affects the cost of external finance and lenders' willingness to provide funds to entrepreneurs.

6 Concluding remarks

This paper developed a theoretical model of a small open economy with access to international capital markets to assess the effects of asymmetric information between borrowers and lenders. The model was calibrated for New Zealand. Only borrowers could costlessly observe actual returns after project completion. The ex post information asymmetry led to agency costs and a moral hazard problem and lowered the probability that a loan would be repaid. Financial intermediaries helped overcome the information asymmetry by lending via a debt contract and monitoring borrowers who default on their debt.

The analysis showed that asymmetric information and agency costs have real economic effects. Information asymmetry between borrowers and lenders raises the cost of external finance and lowers the long-run level of steady state investment, capital and output. The long-run effects of agency costs are exacerbated in an open economy. This is because access to international capital markets increases the opportunity cost of lending to risky borrowers and raises the rate of return lenders demand for the use of their funds. Agency costs and the cost of external finance also impact on the business cycle and the central bank's response to shocks. Following a shock to the economy output rises (falls) more gradually and by less in the presence of agency costs. Output fluctuations are dampened in the agency cost model because shocks to the economy affect the cost of external finance to produce capital and expand production. Without agency costs the cost of external finance and the price of capital are unaffected by these shocks. Furthermore, in an open economy with access to international capital markets the cost of external finance is influenced by the exchange rate and the impact of agency costs is affected by the degree of access to international capital markets.

The findings in this paper have at least three implications. First, they underline the importance of well-functioning financial systems. Financial intermediaries and markets can help reduce asymmetric information in credit markets and thus increase the efficient allocation of resources and long-run economic performance. Minimizing information asymmetry requires the production and discovery of information through screening and monitoring. Policy settings (such as disclosure requirements, accounting standards and financial regulation) are important because they can impact on the effectiveness of financial systems in allocating resources to best uses. Second, macroeconomic models that do not account for asymmetric information in credit markets provide an incomplete description of the economy. Asymmetric information and agency costs have important long-run real economic effects. Moreover, they affect the propagation of shocks to the economy and policy makers' responses to economic fluctuations. Third, credit market interactions are altered in small open economies compared to large closed economies. The effects of agency costs are exacerbated in the open economy and their impact is influenced by the degree of access to international capital markets. This suggests that credit market frictions may change with increases in international capital mobility due to financial liberalization and globalization. The results thus highlight the importnce of incorporating credit market interactions into open economy macroeconomic models.

Acknowledgements

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A Parameterization and steady state

This appendix contains the details of the parameterization and the equations solving for the steady state of the agency cost model.

A.1 Parameterization

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

Labour-augmenting productivity, $\bar{Z}$, is normalized 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, η_l, capital, η_k, and commodity inputs, η_{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 and yield a steady state ratio of imports to output of about 12 percent, the same as in McCallum and Nelson (1999). The capital depreciation rate is set to 8.5 percent per annum, the same as in the Reserve Bank of New Zealand's macroeconomic model (Black, Cassino, Drew, Hansen, Hunt, Rose and Scott, 1997). 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).

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

The annual domestic steady state inflation rate, Π^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, τ, equals 17 percent in line with the income tax assumption in the Reserve Bank's model.

For simplicity, 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 normalized to 1. The price and foreign demand elasticities of exports, κ and ς, are equal to unity, as in McCallum and Nelson (2000) and 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).

A.2 Steady state

The steady state agency cost model can be solved as follows, where $\bar{K}$, $\bar{K}^e$, $\bar{NW}$, $\bar{IN}$, $\bar{C}^h$, $\bar{C}^e$, $\bar{C}$, $\bar{G}$, $\bar{EX}$, $\bar{Y}$, $\bar{L}^h$ and $\bar{IM}$ denote steady state averages:

$$\bar{L}^h = \frac{0.3(1-\eta)}{\eta}$$

$$\Phi\left(\bar{\varpi}\right) = 0.00974$$

$$\bar{\Psi} = \frac{\frac{(1+\bar{I}^*)\bar{Q}}{1+\bar{\Pi}^*}}{1-\alpha\Phi(\bar{\varpi})+\frac{\alpha\phi(\bar{\varpi})f(\bar{\varpi})}{f'(\bar{\varpi})}}$$

$$\bar{IR} = \frac{f(\bar{\varpi})\bar{\Psi}}{1-g(\bar{\varpi})\bar{\Psi}} - 1$$

$$\bar{R} = \frac{\frac{\bar{\Psi}}{\beta}-1}{1-\tau}$$

Using firm's first-order conditions

$$\bar{K} = \bar{Y}\left(\frac{\left(\left(1+(1-\tau)\bar{R}\right)-(1-\delta)\bar{\Psi}\right)\frac{\theta}{\theta-1}}{(1-\tau)\eta_k}\right)^{\frac{1}{\nu-1}}$$

$$\bar{IM} = \bar{Y}\left(\frac{\frac{\theta}{\theta-1}\bar{Q}}{\eta_{im}}\right)^{\frac{1}{\nu-1}}$$

and the production function

$$\bar{Y}^{\nu} = \eta_l \left(\bar{Z}\bar{L}^h\right)^{\nu} + \eta_k \bar{K}^{\nu} + \eta_{im} I\bar{M}^{\nu} + (1 - \eta_l - \eta_k - \eta_{im})$$

$\bar{Y}$ can be derived as

$$\bar{Y} = \left(\frac{\eta_l \left(\bar{Z}\bar{L}^h\right)^{\nu} + (1-\eta_l-\eta_k-\eta_{im})}{1-\eta_k \left(\frac{\left(\left(1+(1-\tau)\bar{R}\right)-(1-\delta)\bar{\Psi}\right)\frac{\theta}{\theta-1}}{(1-\tau)\eta_k} \right)^{\frac{\nu}{\nu-1}} - \eta_{im} \left(\frac{\frac{\theta}{\theta-1}\bar{Q}}{\eta_{im}} \right)^{\frac{\nu}{\nu-1}}} \right)^{\frac{1}{\nu}}$$

$$I\bar{N} = \frac{\delta \bar{K}}{1-\alpha\Phi(\bar{\varpi})}$$

$$N\bar{W} = \frac{I\bar{N}\left(\frac{\left(1+\bar{I}^*\right)\bar{Q}}{1+\bar{\Pi}^*} - g(\bar{\varpi})\bar{\Psi} \right)}{\frac{\left(1+\bar{I}^*\right)\bar{Q}}{1+\bar{\Pi}^*}}$$

$$\bar{K}^e = \frac{N\bar{W} - \frac{(1-\tau)\left(1-\eta_l-\eta_k-\eta_{im}\right)\bar{Y}^{1-\nu}}{\frac{\theta}{\theta-1}}}{\left(1+(1-\tau)\bar{R}\right)}$$

$$\bar{C}^e = N\bar{W}\left(1 + I\bar{R}\right) - \bar{\Psi}\bar{K}^e$$

$$E\bar{X} = 0.11 \cdot \bar{Y}$$

$$\bar{G} = \tau \left(\frac{\bar{Y} - \eta_{im}\bar{Y}^{1-\nu} I\bar{M}^{\nu}}{\frac{\theta}{\theta-1}} \right)$$

$$\bar{C}^h = \frac{\eta\left(\bar{Y} - \bar{C}^e - \bar{G} - E\bar{X} - I\bar{N}\right)}{(1-\eta)}$$

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

$$C\bar{A} = E\bar{X} - \bar{Q}I\bar{M}$$

B Dynamic model

This appendix specifies the inflation process and full capacity, flexible price output, which enter the central bank's reaction function, and the shock processes. It also gives the equations for solving the dynamic agency cost model. Dynamic responses are denoted by lower case letters.

B.1 Inflation process

The inflation process is derived from firms' optimal price setting. Firms' price adjustment follows Calvo (1983) and is assumed to be sluggish. Each period firms can adjust their prices with a constant probability, φ. The expected time between adjustments is thus given by $1/\varphi$. The probability that firms can adjust prices is set to 0.33; that is, prices remain unchanged on average for three quarters.

Following Rotemberg (1987), the representative firm j sets its price to minimize 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 given by $\tilde{P}_t(j) = \theta/(\theta-1) P_t MC_t$ or in logarithmic deviations from steady state as

$$\tilde{p}_t(j) = p_t + mc_t \tag{39}$$

It is the price that the firm would set in the absence of restrictions of adjusting prices.

Firm j's quadratic loss function is given by[20]

$$\min \frac{1}{2} \sum_{k=0}^{\infty} (1-\varphi)^k \beta^k E_t \left[p_t(j) - \tilde{p}_{t+k}(j)\right]^2 \tag{40}$$

and the first-order condition of equation (40) with respect to $p_t(j)$ is

$$p_t(j) \sum_{k=0}^{\infty} (1-\varphi)^k \beta^k - \sum_{k=0}^{\infty} (1-\varphi)^k \beta^k E_t \left[\tilde{p}_{t+k}(j)\right] = 0 \tag{41}$$

[20] Firms' discount factor, β, is assumed to be the same as for households.

or solving for $p_t(j)$

$$p_t(j) = (1 - (1-\varphi)\beta)\,\tilde{p}_t(j) + (1-\varphi)\,\beta E_t\left[p_{t+1}(j)\right] \tag{42}$$

If the number of firms is large, a fraction of firms φ actually adjusts their price each period. Using equation (39) the aggregate price adjustment equation can then be written as

$$\pi_t = \beta E_t\left[\pi_{t+1}\right] + \tfrac{\varphi(1-(1-\varphi)\beta)}{(1-\varphi)} mc_t \tag{43}$$

where $\pi_t = p_t - p_{t-1}$ and inflation is a function of expected future inflation and the real marginal cost. Under price stickiness, the marginal cost, MC_t, is equal to the inverse of firms' mark-up, ξ_t, i.e. $MC_t = 1/\xi_t$. Using $\xi_t / (\theta/(\theta-1)) = \xi_t P_t MC_t / (\theta/(\theta-1)\,P_t MC_t) = P_t/\tilde{P}_t(j)$, $\tilde{Y}_t(j) = (\tilde{P}_t(j)/P_t)^{-\theta} Y_t$, 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

$$mc_t = -\tfrac{1}{\theta}\left(y_t - \tilde{y}_t\right) \tag{44}$$

and the inflation adjustment equation is given

$$\pi_t = \beta E_t\left[\pi_{t+1}\right] + \varrho\left(y_t - \tilde{y}_t\right) \tag{45}$$

where $\varrho = \varphi(1-(1-\varphi)\beta)/\theta(1-\varphi)$ and $\tilde{y}_t$ denotes full capacity, flexible price output. Equation (45) 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.

B.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, i.e. in the absence of any restrictions on adjusting prices. Under price flexibility, firms' mark-up is constant and output is given by

$$\tilde{y}_t = \eta_l \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu z_t + \eta_l \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu \tilde{l}_t^h + \eta_k \left(\frac{\bar{K}}{\bar{Y}}\right)^\nu \tilde{k}_t + \eta_{im} \left(\frac{\bar{IM}}{\bar{Y}}\right)^\nu \tilde{im}_t \tag{46}$$

where $\tilde{l}_t^h$, $\tilde{k}_t$ and $\tilde{im}_t$ denote flexible price household labour, capital and commodity imports.[21] 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 22). 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 (24) and (25) 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 (46) can then be re-written as

$$\tilde{y}_t - \frac{1}{1-\nu} z_t + \frac{\eta_k \left(\frac{\bar{K}}{\bar{Y}}\right)^\nu}{\eta_l (1-\nu) \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu} r_t + \frac{\eta_{im} \left(\frac{\bar{IM}}{\bar{Y}}\right)^\nu}{\eta_l (1-\nu) \left(\frac{\bar{Z}\bar{L}^h}{\bar{Y}}\right)^\nu} q_t = 0 \tag{47}$$

Full capacity, flexible price output is thus a function of labour-augmenting productivity, the rental rate of capital and the real exchange rate.

B.3 Exogenous shocks

The productivity shock, z_t, and the foreign demand shock, y_t^*, are univariate exogenous processes that are normally distributed. They evolve according to

$$z_t = \rho_z z_{t-1} + \epsilon_{z,t}, \quad \text{where} \quad \epsilon_{z,t} \sim i.i.d.\ N\left(0; \sigma_z^2\right) \tag{48}$$

[21] Entrepreneurial labour input is equal to η for all t and drops out.

$$y_t^* = \rho_{y^*} y_{t-1}^* + \epsilon_{y^*,t}, \quad \text{where} \quad \epsilon_{y^*,t} \sim i.i.d.\ N\left(0; \sigma_{y^*}^2\right) \tag{49}$$

The choice of shock parameters follows McCallum and Nelson (2000), except for the autocorrelation coefficient of the foreign demand shock. McCallum and Nelson (2000) assume that the foreign demand shock is a random walk. Here, the autocorrelation coefficient of the foreign demand shock is assumed to be the same as for the productivity shock, i.e. $\rho_{y^*} = \rho_z = 0.95$. The innovation variances are given by $\sigma_z^2 = (0.007)^2$ and $\sigma_{y^*}^2 = (0.02)^2$.

B.4 Dynamic model

The dynamic agency cost model is described by (45) and (47) and the following equations:

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

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

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

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

$$\frac{\frac{(1+\bar{I}^*)\bar{Q}}{1+\bar{\Pi}^*}}{\bar{\Psi}} \psi_t + \frac{\frac{(1+\bar{I}^*)\bar{Q}}{1+\bar{\Pi}^*}}{\bar{\Psi}} q_t + \frac{\frac{(1+\bar{I}^*)\bar{Q}}{1+\bar{\Pi}^*}}{\bar{\Psi}} i_t^* - \frac{\frac{(1+\bar{I}^*)\bar{Q}}{1+\bar{\Pi}^*}}{\bar{\Psi}} \pi_t^* + \frac{f(\bar{\varpi})}{f'(\bar{\varpi})} \left(\frac{\phi'(\bar{\varpi})}{\phi(\bar{\varpi})} - \frac{f''(\bar{\varpi})}{f'(\bar{\varpi})}\right) \alpha \phi\left(\bar{\varpi}\right) \bar{\varpi} \boldsymbol{\varpi}_t = 0$$

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

$$\frac{(1-\tau)(1-\nu)(1-\eta_l-\eta_k-\eta_{im})\bar{Y}^{1-\nu}}{\frac{\theta}{\theta-1}} y_t + \frac{(1-\tau)(1-\eta_l-\eta_k-\eta_{im})\bar{Y}^{1-\nu}}{\frac{\theta^2}{\theta-1}} \left(y_t - \tilde{y}_t\right)$$
$$+ \left(1 + (1-\tau)\, \bar{R}\right) \bar{K}^e k_{t-1}^e + \left(1 + (1-\tau)\, \bar{R}\right) \bar{K}^e r_t - \bar{N}\bar{W} nw_t = 0$$

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

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

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

$$\frac{\tau\left(\bar{Y}-\eta_{im}(1-\nu)\bar{Y}^{1-\nu}\bar{IM}^\nu\right)}{\frac{\theta}{\theta-1}}y_t+\frac{\tau\left(\bar{Y}-\eta_{im}\bar{Y}^{1-\nu}\bar{IM}^\nu\right)}{\frac{\theta^2}{\theta-1}}\left(y_t-\tilde{y}_t\right)$$
$$-\frac{\tau\eta_{im}\nu\bar{Y}^{1-\nu}\bar{IM}^\nu}{\frac{\theta}{\theta-1}}im_t-\bar{G}g_t=0$$

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

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

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

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

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

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

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

$$i_t-\mu_1\pi_t-\mu_2\left(y_t-\tilde{y}_t\right)-\mu_3 i_{t-1}=0$$

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 μ_1 and μ_2 is based on the parameter values in a Taylor rule (Taylor, 1993). The coefficient on the lagged interest rate, μ_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.

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