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Internationalised Production in a Small Open Economy*

Aurélien Eyquem and Güneş Kamber†

Abstract

We show that internationalised production, modelled as trade in intermediate goods, brings the dynamics of a small open economy closer to that observed in the data. We build a stylized new-Keynesian small open economy model and we show that when production is internationalised, movements of international relative prices affect the economy through an additional channel, denoted as the "cost channel". Both qualitatively and quantitatively, this channel (i) increases the share of output variance explained by foreign shocks, consistent with empirical evidence, (ii) implies that the exchange rate pass-through is closer to estimated values, and (iii) increases the international correlation of output relative to that of consumption.

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1 Introduction

Recently the New Keynesian synthesis models have been extensively applied to the study of monetary policy in small open economies.[1] These models, enriched with many frictions such as habit formation in consumption, price and wage indexation, also became the workhorse of applied macroeconomic analysis. Most of these models assume that the traded good is a consumption good. However, the data reveals that a non-negligible part of trade occurs at the intermediate goods level. For instance Feenstra (1998) and Hummels, Ishii, and Yi (2001) show that the internationalisation of production processes has dramatically increased over the last thirty years. Indeed recent European Monetary Union data confirm that intermediate goods trade is a major component of total trade, since the degree of intra-zone openness is 4.39% for capital goods, 16.46% for intermediate goods and 9.22% for consumption goods.[2] Moreover, for most inflation targeting small open economies trade of the intermediate imports represents approximately half of their total trade flows. For example, during the last ten years, the average share of intermediate goods imports in total imports has been around 45% for New Zealand and Australia, and 56% for Chile.[3] These numbers imply that the international transmission of shocks may not only be through consumption and labour supply decisions of households but also through the internationalisation of production structures.

Despite this empirical observation, little attention has been paid to the role of imported producer inputs in determining business cycle properties of small open economies. This paper aims to fill this gap by analysing the role of intermediate goods trade within a dynamic stochastic general equilibrium model of a small open economy with imperfect competition and nominal rigidities. Our model closely follows Galí and Monacelli (2005) except that we allow the intermediate good to be traded internationally. The consumption good is thus produced using a composite index of intermediate goods produced in the domestic economy and in the rest of the world. The intensity with which foreign imports are used in the production of consumption goods is governed by one parameter of the final goods production function. Therefore, we can analyse the role of various levels of intermediate trade on business cycles

[1] Some important contributions comprise Clarida, Gali, and Gertler (2001), Galí and Monacelli (2005), McCallum and Nelson (2000), Monacelli (2005), Corsetti and Pesenti (2001), Smets and Wouters (2002).

[2] Data available at http://sdw.ecb.europa.eu/.

[3] Data available from Haver Analytics.

properties of key domestic variables such as output, inflation and exchange rates.

We document an additional channel through which movements of relative prices and exchange rates are passed through domestic macroeconomic variables. As long as intermediate output can be sold internationally, movements in exchange rates modify the demand for domestically produced intermediate goods. Since the relative price of intermediate goods enters the marginal cost of consumption goods producers and, *via* the Phillips Curve, modifies inflation dynamics, exchange rates exert an effect on inflation and output through this additional channel, denoted as the "cost channel". We show that the magnitude of this channel depends on the level of internationalisation of production and on the elasticity of substitution between imported and domestically produced intermediate goods in the production function.

We find that the assumption of intermediate goods trade has major consequences on the macroeconomic dynamics caused by standard shocks – such as both domestic and foreign productivity and monetary shocks, and provides new insights concerning the characteristics of business cycles in a small open economy.

First, the share of domestic variables variances explained by foreign shocks increases by several orders of magnitude. Indeed, standard small open economy DSGE models are mostly unable to account for the observed large effects foreign shocks have on domestic variables of small open economies. For instance, Justiniano and Preston (2010) estimate a small open economy DSGE model on Canadian data and find that the share of foreign shocks in the variance decomposition is virtually zero. On the contrary, empirical studies suggest that foreign shocks play an important role in the domestic business cycle of small open economies. For instance, Kose, Otrok, and Whiteman (2003) document that world factors have a substantial role in country-level economic fluctuations. At the individual country-level, Justiniano and Preston (2010) for Canada and Karagedikli and Thorsrud (2010) for New Zealand, find a sizeable share of foreign shocks in the variance decomposition of domestic variables.

Second, the exchange rate pass-through is reduced and more consistent with the data when trade occurs at the intermediate level. This result can be seen as complementary to that of McCallum and Nelson (2000), as it is obtained in a more general framework.

Third, in line with Huang and Liu (2007), internationalised production increases significantly the correlation of domestic output with world output. While the international correlation of national output is high in the data, and greater than the correlation of private consumption, most models fail in reproducing this feature of the data (see Backus, Kehoe, and Kydland (1993)). This failure is often referred to as the output-consumption anomaly. The assumption of trade in intermediate goods and the introduction of the "cost channel" partly helps reproducing this feature of the data, although consumption remains more correlated than output.

Finally, incompleteness of international financial markets is investigated as an extension. While most results are qualitatively preserved under this assumption, the effects of trade in intermediate goods are attenuated and the quantitative properties of the model do not improve.

The remainder of the paper is organized as follows. Section 2 summarizes some related literature. Section 3 details the theoretical model. Section 4 presents the steady state and derives a log-linearized version of the model. Section 5 analyses the dynamics of the economy after standard domestic and foreign productivity and monetary shocks. Section 6 discusses the cyclical properties of the model. Section 7 proceeds to an extensive sensitivity analysis. Section 8 presents an extension of the model with incomplete international financial markets and investigates its business cycles properties. Section 9 concludes.

2 Related literature

Theoretically, Findlay and Rodriguez (1977) are among the first to study the economic policy implications of introducing an imported intermediate input into an open economy model. They focus on fiscal policy issues in an otherwise standard Mundell-Fleming model and show that oil trade may give some stabilisation power to fiscal policy even in a flexible exchange rate system. More recently, several authors consider the role of multinational production on the dynamics of inflation and exchange rates and on the design of monetary policy.[4] In most of these contributions, prices are preset and monetary aggregates are considered as the monetary policy instruments. In contrast,

[4] See for example Cavallari (2004), Shi and Xu (2007), Devereux and Engel (2007).

our model allows for staggered price setting *à la* Calvo and monetary policy is conducted using interest rate rules, as in most modern central banks.

The closest to our model is Huang and Liu (2007) who consider the role of intermediate goods trade with multiple stages of processing in a two-country model. They show that their model can improve the standard open-economy model in several dimensions. However, the focus of their paper, is the change in the transmission of monetary policy shocks under internationalised production. Instead, our focus in this paper is the transmission of both productivity and monetary policy shocks. In addition, they only focus on the correlations of domestic variables with foreign variables while we consider a wider set of business cycles properties.

Finally, McCallum and Nelson (2000) consider a model in which imports are solely used in the production process, together with domestic labour . International trade thus occurs only at the intermediate goods level and, thus producer price inflation and consumer price inflation are perfectly identical. McCallum and Nelson (2000) argue that this simple setting is able to replicate the stylized fact about the exchange rate pass-through to prices, which is lower in the data than in standard models, such as Galí and Monacelli (2005). Our model can be seen as a generalisation of their model, in which we can calibrate the share of intermediate goods trade in total trade flows to intermediate values, as well as the elasticity of substitution between traded inputs.

3 The model

Our model closely follows Galí and Monacelli (2005) except for the role of the intermediate goods sector and for the endogenous adjustment of the world economy. The world economy is formed by a continuum of small open economies. The optimality conditions characterising the optimal decision of households and firms are identical across countries and the size of each economy is small relative to the rest of the world. In terms of notation, the counterpart of a variable y in domestic economy is noted y^* for the rest of the world.

Households The home country is populated by infinitely-living households whose number is normalized to one. The representative household of the

home country maximizes the following welfare index

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, n_t\right) \tag{1}$$

subject to the budget constraint

$$E_t\left\{\ell_{t,t+1} b_{t+1}\right\} + p_t c_t = b_t + \chi_t + w_t n_t + T_t \tag{2}$$

and subject to the appropriate transversality condition on the portfolio. Let λ_t denote the multiplier associated with the budget constraint.

In equation (1), the parameter β is the subjective discount factor, c_t denotes the aggregate consumption, and n_t the quantity of labour competitively supplied to the firms. In (2), w_t is the nominal wage rate, $\chi_t = \int_0^1 \chi_t(j)dj$ denotes the claims on consumption goods producers' profits, b_t is the value of a portfolio of state contingent assets held in period $t-1$, $\ell_{t,t+1}$ is the stochastic discount factor for one-period ahead nominal payments attached to the portfolio, and p_t is the consumer price index (CPI). Finally, T_t is a lump-sum transfer.

The representative household chooses c_t, n_t, and b_{t+1}. First order conditions imply

$$-\frac{u_{n,t}}{u_{c,t}} - \frac{w_t}{p_t} = 0 \tag{3}$$

$$\beta\left(\frac{u_{c,t+1}}{u_{c,t}}\right)\left(\frac{p_t}{p_{t+1}}\right) = \ell_{t,t+1}. \tag{4}$$

Equation (3) is a standard open-economy labour supply function, describing the intratemporal trade-off between consumption and leisure by equating the marginal rate of substitution between consumption and leisure to the real wage. Equation (4) is the Euler equation relating the intertemporal choice of consumption as a function of the CPI inflation rate and the return on the financial portfolio. Denoting $r_t = \frac{1}{E_t\{\ell_{t,t+1}\}}$ as the gross return on a risk-less one-period bond, and taking conditional expectations on both sides of (4), the standard Euler equation writes

$$r_t \beta E_t\left\{\left(\frac{u_{c,t+1}}{u_{c,t}}\right)\left(\frac{p_t}{p_{t+1}}\right)\right\} = 1.$$

As in Galí and Monacelli (2005), we assume home bias in the final consumption bundles. The aggregate consumption index includes consumption of goods produced in the home country (h) and consumption of goods produced in the rest of the world (f)

$$c_t = \left[(1-\alpha)^{\frac{1}{\mu}} (c_{h,t})^{\frac{\mu-1}{\mu}} + \alpha^{\frac{1}{\mu}} (c_{f,t})^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}}.$$

We assume that the law of one price holds. The companion consumption price index is thus

$$p_t = \left[(1-\alpha) (p_{h,t})^{1-\mu} + \alpha (p_{f,t})^{1-\mu}\right]^{\frac{1}{1-\mu}}$$

where $(1-\alpha) \in [0,1]$ is the home bias in consumption. α also measures the share of imported consumption goods in total consumption, and thereby is directly related to the degree of openness of consumption goods markets. In these expressions, μ is the elasticity of substitution between domestic and foreign goods.

Assuming that firms do not discriminate between domestic and foreign markets, the law of one price holds, and the domestic price of a foreign final good is

$$p_{f,t} = \varepsilon_t p^*_{f,t}$$

where ε_t is the nominal exchange rate, defined as the price of a unit of the foreign currency in terms of the domestic currency.

The terms of trade and the real exchange rate are respectively[5]

$$s_t = \frac{\varepsilon_t p^*_{f,t}}{p_{h,t}}, \text{ and } q_t = \frac{\varepsilon_t p^*_t}{p_t}.$$

The standard Dixit and Stiglitz (1977) consumption subindexes are

$$c_{h,t} = \left[\int_0^1 c_{h,t}(j)^{\frac{\theta-1}{\theta}} dj\right]^{\frac{\theta}{\theta-1}}, \qquad c_{f,t} = \left[\int_0^1 c_{f,t}(j)^{\frac{\theta-1}{\theta}} dj\right]^{\frac{\theta}{\theta-1}}$$

where $c_{h,t}(j)$ ($c_{f,t}(j)$) is the consumption of a typical variety j produced in the home country (in rest of the world) by the representative consumer and $\theta > 1$ is the elasticity of substitution between varieties of consumption goods.

[5] The definition of the terms of trade is consistent with the definition of the real exchange rate.

The optimal allocation of consumption between home and foreign goods gives rise to demand functions according to which individual consumptions depend on the relative price of each good and on the aggregate level of consumption

$$c_{h,t} = (1-\alpha)\left(\frac{p_{h,t}}{p_t}\right)^{-\mu} c_t, \qquad c_{f,t} = \alpha\left(\frac{p_{f,t}}{p_t}\right)^{-\mu} c_t.$$

Accordingly, optimal variety demands depend on the relative prices of varieties and on the aggregate level of consumption for home and foreign goods

$$c_{h,t}(j) = \left(\frac{p_{h,t}(j)}{p_{h,t}}\right)^{-\theta} c_{h,t}, \qquad c_{f,t}(j) = \left(\frac{p_{f,t}(j)}{p_{f,t}}\right)^{-\theta} c_{f,t}.$$

Risk-sharing Under the assumption of complete international markets of state-contingent assets, a relation similar to equation (4) holds in the rest of the world

$$\beta\left(\frac{u_{c^*,t+1}}{u_{c^*,t}}\right)\left(\frac{p_t^*}{p_{t+1}^*}\right)\left(\frac{\varepsilon_t}{\varepsilon_{t+1}}\right) = \ell_{t,t+1}$$

which, combined with equation (4) gives the following risk-sharing condition

$$\frac{u_{c,t}^*}{u_{c,t}} = \epsilon\frac{\varepsilon_t p_t^*}{p_t} \tag{5}$$

Equation (5) states that relative marginal utilities are related to the real exchange rate up to a constant, ϵ, that depends on initial conditions for the relative net foreign asset position. Assuming symmetric initial conditions simply amounts to setting $\epsilon = 1$, which is consistent with the symmetric steady state around which we study the dynamic properties of the model. Finally, combining both Euler equations with (5) implies that the uncovered interest rate parity holds

$$r_t = r_t^* E_t\left\{\varepsilon_{t+1}\right\}/\varepsilon_t.$$

Firms Two types of producers operate in this economy: Intermediate goods producers and consumption goods producers. Both in the small open economy and in the rest of the world, intermediate goods producers operate in perfectly competitive markets. Intermediate goods producers use domestic labour according to a linear production function

$$x_t = a_t l_t$$

where a_t is the productivity of labour, following an AR(1) process with iid innovations of constant variance. Firms sell their products exactly at their nominal marginal production cost, w_t/a_t. Consumption goods producers operate in monopolistically competitive markets. Each producer is the single supplier of a variety, produced by combining domestic and foreign intermediate goods according to

$$y_t(j) = \left[(1-\gamma)^{\frac{1}{\phi}} \left(x_{h,t}(j)\right)^{\frac{\phi-1}{\phi}} + \gamma^{\frac{1}{\phi}} \left(x_{f,t}(j)\right)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}. \tag{6}$$

In equation (6), $x_{h,t}(j)$ $(x_{f,t}(j))$ is the quantity of intermediate goods produced in the home country (in the rest of the world) demanded by consumption goods producer j in the home country. $(1-\gamma) \in [0,1]$ is the home bias in the production of consumption goods and ϕ is the elasticity of substitution between intermediate goods produced in the home country and in the rest of the world. As long as $\gamma > 0$, consumption goods producers trade intermediate goods along the production process, and the production is internationalised. As the law of one price also holds for intermediate goods, the nominal marginal production cost of final goods is

$$mc_t = \left[(1-\gamma)\left(w_t/a_t\right)^{1-\phi} + \gamma\left(\varepsilon_t w_t^*/a_t^*\right)^{1-\phi}\right]^{\frac{1}{1-\phi}}.$$

Prices of consumption goods producers are governed by Calvo (1983) contracts. Each period, a fraction $(1-\eta)$ of randomly selected firms are allowed to set new prices while the remaining fraction η of firms keep selling prices unchanged. The corresponding optimal price set by a typical domestic firm allowed to reset its price is

$$\overline{p}_{h,t}(j) = \varphi \frac{\sum_{v=0}^{\infty} (\eta\beta)^v E_t\left\{\lambda_{t+v} y_{t+v}(j) mc_{t+v}\right\}}{\sum_{v=0}^{\infty} (\eta\beta)^v E_t\left\{\lambda_{t+v} y_{t+v}(j)\right\}}$$

where $y_t(j)$ is the aggregate demand addressed to firm j and $\varphi = \frac{\theta}{(\theta-1)(1-\tau)}$ is the steady state mark-up characterising the distortion of the first-best allocation caused by monopolistic competition. τ is a constant tax/subsidy that may compensate this distorting effects. Aggregating among final firms and given that Calvo producers set the same price when authorized to reset, the aggregate production price index is

$$p_{h,t} = \left[(1-\eta)\,\overline{p}_{h,t}(j)^{\,1-\theta} + \eta p_{h,t-1}^{1-\theta}\right]^{\frac{1}{1-\theta}}.$$

Rest of the world The rest of the world is characterised by identical equilibrium conditions but is considered as a closed economy, i.e. the small open economy does not impact on the rest of the world.

Equilibrium We define aggregate output as $y_t = \left[\int_0^1 y_t(j)^{\frac{\theta-1}{\theta}} dj\right]^{\frac{\theta}{\theta-1}}$. The assumption that the small open economy has negligible effects on the CPI in the rest of the world implies $p^*_{c,t} \simeq p^*_t$. Similarly, the domestic economy is too small to affect the marginal cost of foreign consumption goods producers, i.e. $mc^*_t = w^*_t/a^*_t$. Consequently, using the definition of CPIs, the definition of consumption goods terms of trade and making use of the risk-sharing condition, *i.e.* $u^*_{c,t}/u_{c,t} = q_t$, we can eliminate foreign consumption from the market clearing condition of consumption goods produced in the domestic economy

$$y_t = f(c_t, q_t) = g(c_t, s_t).$$

The market clearing condition of consumption goods produced in the rest of the world yields

$$y^*_t = c^*_t.$$

By the same reasoning, the market clearing condition of intermediate goods produced in the domestic economy is

$$x_t = (1-\gamma)\left((1-\gamma) + \gamma\rho_t^{1-\phi}\right)^{\frac{\phi}{1-\phi}} y_t + \gamma\rho_t^{\phi} y^*_t$$

where ρ_t denotes the intermediate goods terms of trade, defined as

$$\rho_t = \frac{\varepsilon_t w^*_t/a^*_t}{w_t/a_t}.$$

The market clearing condition of intermediate goods produced in the rest of the world is

$$x^*_t = a^*_t l^*_t = y^*_t.$$

Finally, labour market clearing conditions are

$$n_t = l_t, \quad n^*_t = l^*_t.$$

4 Dynamic properties

Preferences Considering the dynamic properties of the model requires specifying the utility function of the households. We assume constant relative risk aversion (CRRA) separable preferences

$$\begin{cases} u(c_t, n_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{n_t^{1+\psi}}{1+\psi} \text{ if } \sigma > 1 \\ u(c_t, n_t) = \log c_t - \frac{n_t^{1+\psi}}{1+\psi} \text{ if } \sigma = 1 \end{cases}$$

where σ is the inverse of the intertemporal elasticity of substitution in consumption and ψ is the inverse of the elasticity of labour supply.

Steady state In the steady state, $x_t = x$, $\forall x$. We focus on a symmetric steady state and assume $c^* = c$ to get $s = q = 1$. Furthermore, assuming $\tau = (1-\theta)^{-1}$, such that the tax rate is chosen to eliminate distortions emerging from the existence of monopoly power, the steady state is characterised by,

$$r = \beta^{-1},\ y = c = a^{\frac{1+\psi}{\psi+\sigma}},\ n = a^{\frac{1-\sigma}{\psi+\sigma}}.$$

Log-linearization We log-linearize the model around the steady state. A hat denotes the log-deviation of a variable from its steady state. The log-linearized equilibrium conditions are given in Table 1.

Monetary policy The model is closed by assuming that monetary policy is conducted through a standard Taylor-type nominal interest rate rule

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1-\rho_r)(\varphi_\pi \widehat{\pi}_t + \varphi_y \widehat{y}_t) + \xi_{r,t}$$

where $\xi_{r,t}$ is the i.i.d. monetary policy innovation.

We also check the robustness of our results in the case where the central bank targets fluctuations of the Producer Pricer Index (PPI) inflation rate, i.e.

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1-\rho_r)(\varphi_\pi \widehat{\pi}_{h,t} + \varphi_y \widehat{y}_t) + \xi_{r,t}.$$

In the foreign economy, as $p_t^* = p_{f,t}^*$, monetary policy is just

$$\widehat{r}_t^* = \rho_r \widehat{r}_{t-1}^* + (1-\rho_r)(\varphi_\pi \widehat{\pi}_t^* + \varphi_y \widehat{y}_t^*) + \xi_{r^*,t}.$$

Parameterization Table 2 summarizes the value of parameters used in the rest of the paper. The model is quarterly. We assume $\beta = 0.99$, implying an

Table 1. The log-linearized model

Euler equation and risk sharing
$\sigma E_t\left\{\widehat{c}_{t+1}\right\} - \sigma\widehat{c}_t = \widehat{r}_t - E_t\left\{\widehat{\pi}_{h,t+1} + \alpha\Delta\widehat{s}_{t+1}\right\}$
$\sigma\left(\widehat{c}_t - \widehat{c}_t^*\right) = (1-\alpha)\,\widehat{s}_t$
NK Phillips curves
$\widehat{\pi}_{h,t} = \beta E_t\left\{\widehat{\pi}_{h,t+1}\right\} + \frac{(1-\eta\beta)(1-\eta)}{\eta}\left(\psi\widehat{n}_t + \sigma\widehat{c}_t - \widehat{a}_t + \alpha\widehat{s}_t + \gamma\widehat{\rho}_t\right)$
$\widehat{\pi}_{f,t}^* = \beta E_t\left\{\widehat{\pi}_{f,t+1}^*\right\} + \frac{(1-\eta\beta)(1-\eta)}{\eta}\left(\psi\widehat{n}_t^* + \sigma\widehat{c}_t^* - \widehat{a}_t^*\right)$
Consumption goods market clearing
$\widehat{y}_t = \widehat{c}_t + \sigma^{-1}\alpha\left(\sigma\mu + (1-\alpha)\left(\sigma\mu - 1\right)\right)\widehat{s}_t$
$\widehat{y}_t^* = \widehat{c}_t^*$
Intermediate goods market clearing
$\widehat{a}_t + \widehat{n}_t = (1-\gamma)\,\widehat{y}_t + \gamma\widehat{y}_t^* + \phi\gamma\left(1 + (1-\gamma)\right)\widehat{\rho}_t$
$\widehat{a}_t^* + \widehat{n}_t^* = \widehat{y}_t^*$
Terms of trade and exchange rates
$\widehat{\rho}_t = (1-\alpha)\,\widehat{s}_t + \psi\left(\widehat{n}_t^* - \widehat{n}_t\right) + \sigma\left(\widehat{c}_t^* - \widehat{c}_t\right) - \left(\widehat{a}_t^* - \widehat{a}_t\right)$
$\widehat{q}_t = (1-\alpha)\,\widehat{s}_t$
$\Delta\widehat{s}_t = \Delta\widehat{\varepsilon}_t + \widehat{\pi}_{f,t}^* - \widehat{\pi}_{h,t}$
$E_t\left\{\Delta\widehat{\varepsilon}_{t+1}\right\} = \widehat{r}_t - \widehat{r}_t^*$
Exogenous shocks
$\widehat{a}_t = \rho_a\widehat{a}_{t-1} + \xi_{a,t}$
$\widehat{a}_t^* = \rho_{a^*}\widehat{a}_{t-1}^* + \xi_{a^*,t}$

annual steady state real interest rate of 4%. We adopt a log-utility function in consumption by setting $\sigma = 1$. Canzoneri, Cumby, and Diba (2007) recall that estimates of the Frisch elasticity $(1/\psi)$ range from 0.05 to 0.35. Macroeconomic models typically use much higher values for the elasticity of labour supply. We thus set the parameter governing the disutility of labour to $\psi = 2$, which can be seen as conservative since the implied Frisch elasticity $(1/\psi = 0.5)$ lays on the upper bound of the values put forth by Canzoneri, Cumby, and Diba (2007). Since the values of σ and ψ are subject to empirical controversies, a full sensitivity analysis with respect to these parameters will be conducted. In accordance with aggregate estimates, we set the elasticity of substitution between domestic and foreign goods in the aggregate consumption bundle to $\mu = 1.5$. This value is fairly standard and aims at matching the volatility of the trade balance (see Backus, Kehoe, and Kydland (1993)). It is worth emphasizing that we depart from the case where the domestic economy is fully insulated from foreign shocks, namely the case where $\sigma = \mu = 1$. In the intermediate sector production function, we also assume that $\phi = 1.5$. Again, as the values of

Table 2. Parameters value

Discount factor	$\beta = 0.99$
Risk aversion	$\sigma = 1$
Elasticity of labour supply	$\frac{1}{\psi} = \frac{1}{2}$
Total trade openness	$\alpha + \gamma = 0.4$
Intermediate goods trade openness	$\gamma \in [0, 0.4]$
Consumption goods trade openness	Adjusted
Elasticity of substitution of intermediate goods	$\phi = 1.5$
Elasticity of substitution of consumption goods	$\mu = 1.5$
Duration of price contracts	$\frac{1}{1-\eta} = 4$
Persistence of monetary policy changes	$\rho_r = 0.7$
Reaction of monetary policy to inflation	$\varphi_\pi = 1.5$
Reaction of monetary policy to output	$\varphi_y = 0.125$
Persistence of productivity shocks	$\rho_a = \rho_{a^*} = 0.9$
Standard deviation of productivity innovations	$\sigma(\xi_a) = \sigma(\xi_{a^*}) = 1\%$
Standard deviation of monetary innovations	$\sigma(\xi_r) = \sigma(\xi_{r^*}) = 0.25\%$

trade elasticities are much debated in the empirical literature, we conduct a full sensitivity analysis with respect to these parameters. Under all versions of the model, we keep the share of imports in total production equal to 0.4. As a consequence, when production is not internationalised, we set $\alpha = 0.4$. When we account for intermediate goods trade, *i.e.* when γ is positive, we adjust α to keep the share of total imports in output constant. In our baseline calibration, we consider that half of the imports are intermediate goods imports, i.e. $\alpha = \gamma = 0.2$. We set the price rigidity parameter to $\eta = 0.75$ implying that the average duration of prices of is 4 quarters. Concerning the monetary policy rules, the smoothing parameter is $\rho_r = 0.7$, the elasticity of the nominal interest rate to the inflation rate is $\varphi_\pi = 1.5$ and the elasticity to output is $\varphi_\pi = 0.125$ (see Clarida, Gali, and Gertler (2001)). Finally, the persistence and standard deviations of productivity shocks are set to standard values, i.e. $\rho_a = \rho_{a^*} = 0.9$, and $\sigma(\xi_a) = \sigma(\xi_{a^*}) = 0.01$. The standard deviations of monetary shocks are $\sigma(\xi_r) = \sigma(\xi_{r^*}) = 0.0025$, consistent with the estimates of Canzoneri, Cumby, and Diba (2007). Notice that the spillovers of productivity shocks, as well as the correlations of both monetary and productivity innovations are set to zero since we seek to identify the international transmission mechanisms of foreign shocks to the domestic economy. We thus abstract from introducing exogenous sources of shocks' transmission.

5 Impulse Response Functions

In this section, we analyse the dynamic response of our model economy to domestic and foreign shocks. We report the impulse response functions (IRFs) of the model in the benchmark case ($\gamma = 0$) and with trade in intermediate goods ($\gamma = 0.2$ and $\gamma = 0.4$).

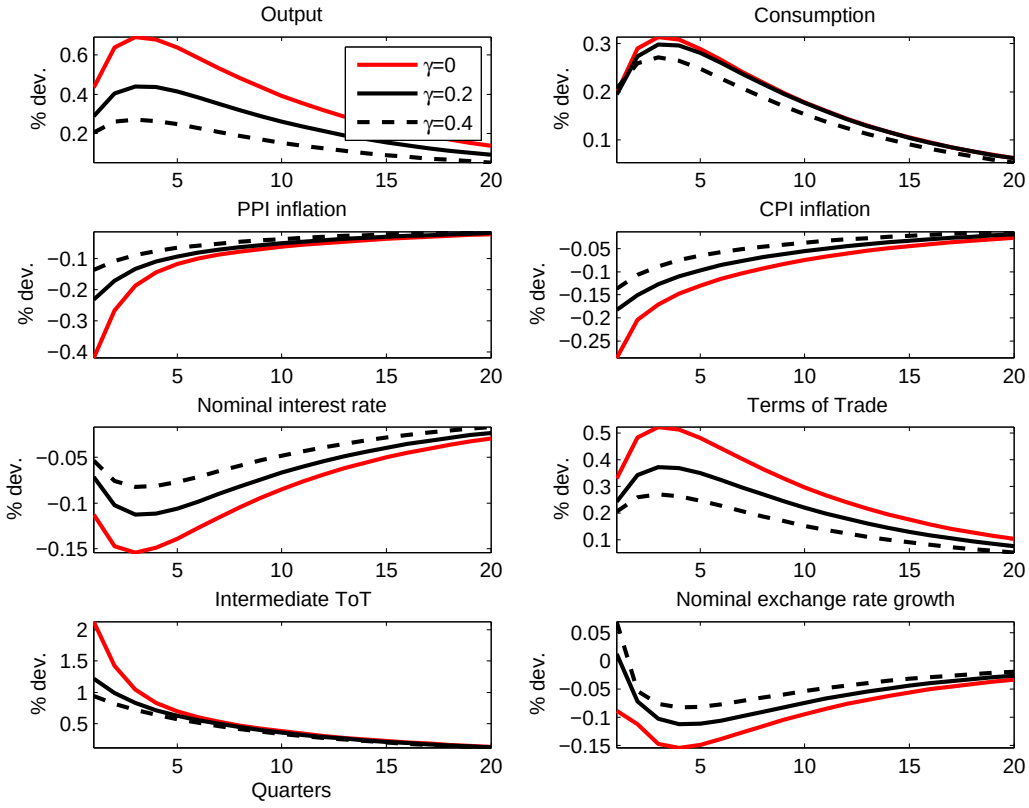
5.1 Productivity shocks

Domestic productivity shock Figure 1 displays the IRFs of key variables to a unit domestic productivity shock. Under all calibrations the impulse responses are qualitatively similar. A positive technology shock is associated with an increase in output and consumption alongside a fall in inflation. The nominal interest rate falls in order to support the increase in output and consumption. The fall in the interest rate yields a depreciation of the nominal exchange rate, which, combined with the drop of domestic PPI inflation, implies a significant real depreciation.

The responses differ, however, quantitatively. The impulse responses are lower in magnitude when allowing for trade in intermediate goods. When $\gamma = 0$, the effect of productivity shocks on inflation are governed by their effects on the marginal cost of consumption goods producers. The fall in real marginal cost yields a decrease in the PPI inflation rate. When $\gamma > 0$, besides the direct marginal cost effect, our model displays an additional channel through which inflation dynamics are affected, originating from the depreciation of the nominal exchange rate. The deterioration of the terms of trade in the intermediate goods sector (ρ_t increases) makes the foreign intermediate goods more costly to acquire from the perspective of domestic firms. Hence, the fall in marginal cost is balanced by more expensive foreign intermediate goods. The lower reaction of marginal cost reduces the size of adjustment in inflation and in all other variables. This second round effect is absent in most New Keynesian models. For instance, in response to the same technology shock the boost in output under internationalised production is dramatically reduced as compared to the increase without internationalised production.

Foreign productivity shock Figure 2 displays the IRFs of key variables to a unit foreign productivity shock. Contrary to the case of a domestic produc-

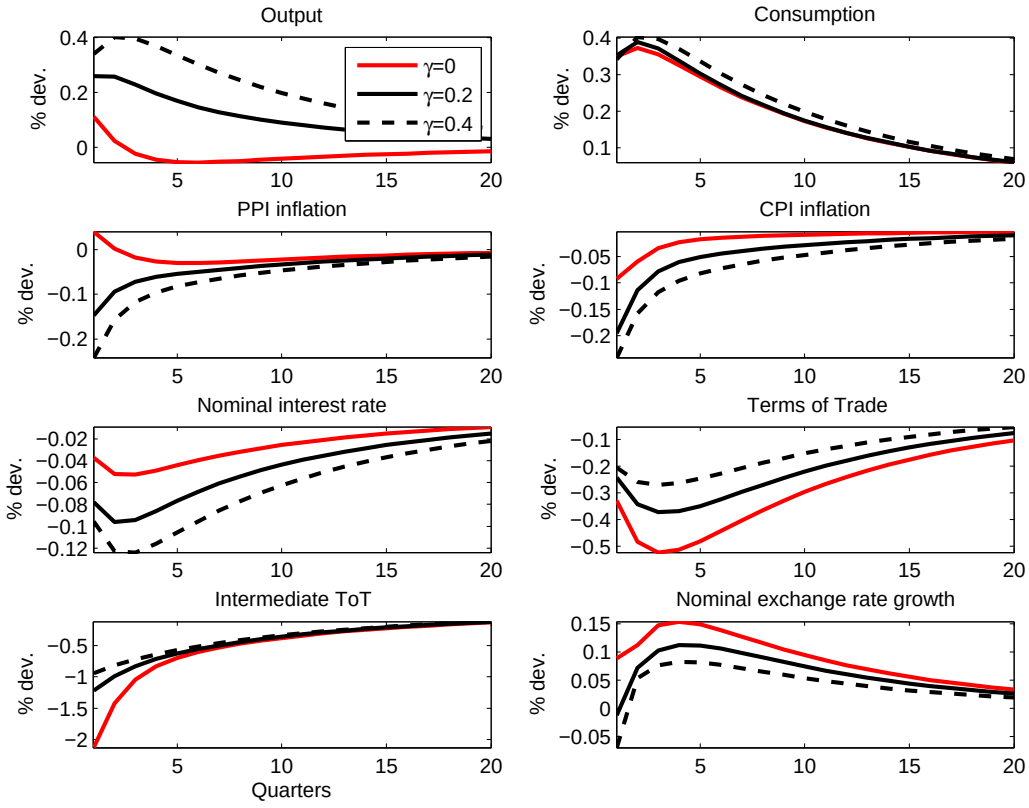
Figure 1
Impulse responses to a domestic technology shock



tivity shock, internationalised production changes the dynamics of domestic variables after a foreign productivity shock.

When $\gamma = 0$, the domestic output decreases and inflation increases, while consumption rises and the terms of trade (directly related to the real exchange rate) improve (s_t decreases). In this case, the foreign productivity shock increases the wealth of foreign households and the risk-sharing condition requires a real appreciation to increase the wealth of domestic agents. Consumption rises because imports of final goods are cheaper but the expenditure switching lowers the demand for final goods produced in the domestic economy and output shrinks. Finally, the increase in households' wealth provides a clear incentive for them to cut their labour supply, inducing an increase in the marginal production cost of final goods and leading PPI inflation to rise. CPI inflation drops however, due to the appreciation of the

Figure 2
Impulse responses to a foreign technology shock



real exchange rate, and triggers a drop of the interest rate.

When $\gamma > 0$, fluctuations of the final and intermediate goods terms of trade now generate intermediate goods trade flows and affect the real marginal cost of domestic consumption goods producers. In particular, the fall of exports in intermediate goods leads to a decrease in wages. At the same time, since the competitiveness of domestic intermediate goods producers drops, intermediate goods from the rest of the world are less costly from the perspective of domestic final goods producers. Domestic producers thus use foreign intermediate goods more intensively. The combination of the drop in wages and the expenditure switching effect at the production stage leads to a decrease in the domestic marginal cost, implying a drop of PPI inflation and an increase in output. The dynamics of other variables, such as consumption, CPI inflation or terms of trade remains qualitatively similar although

quantitatively different. Since PPI inflation drops, the decrease in CPI inflation is magnified, as well as that of the nominal interest rate. This amplifies the increase in consumption and reduces the need for real exchange rate and terms of trade appreciation implied by the risk-sharing condition.

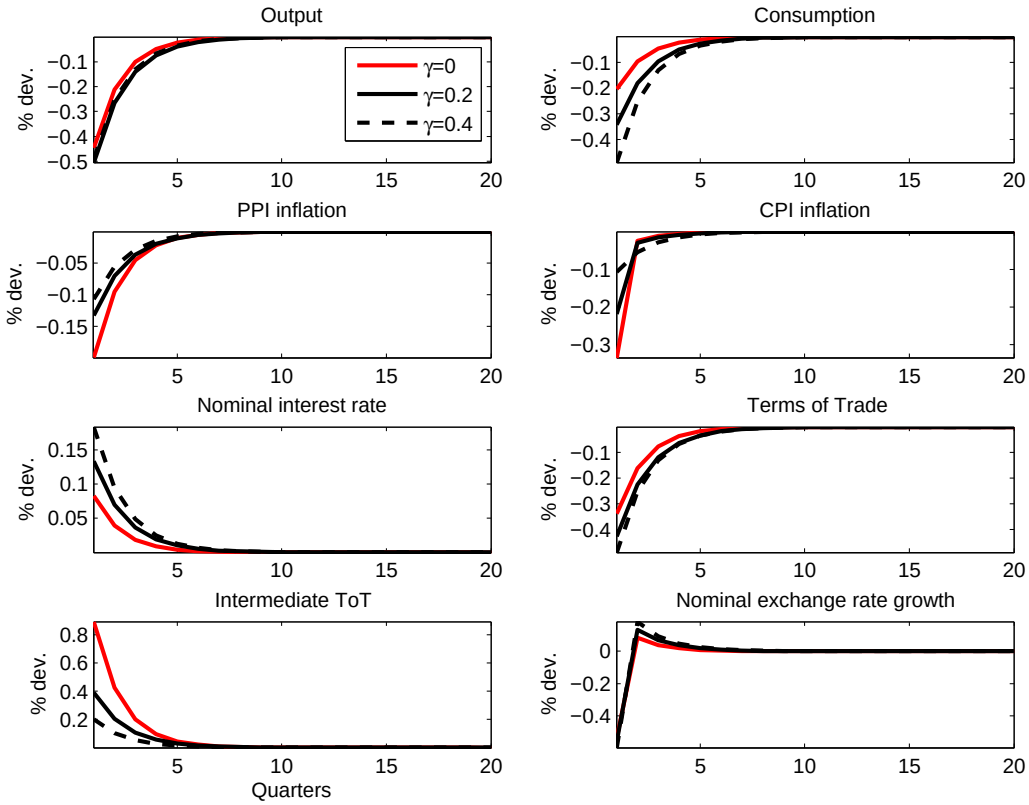
Trade in intermediate goods thus makes a case for positive international transmission of foreign productivity shocks relying on endogenous transmission mechanisms. Also, this positive transmission does not resort to implausible values of σ and μ, which determines the sign of the response of the trade balance to changes in the real exchange rate. Typically, in the baseline New-Keynesian model, a positive international transmission in output after a foreign productivity shock requires a positive response of the trade balance to a real appreciation. This is the case when $\sigma\mu < 1$, which implies $\mu < 1$.

5.2 Monetary policy shocks

Domestic monetary policy shock Figure 3 displays the IRFs of key variables to a unit domestic monetary policy shock.

The effects of a tightening in domestic monetary policy are qualitatively similar whether trade in intermediate goods is considered or not. In response to an increase in the nominal interest rate, private consumption is depressed as households substitute future consumption for present consumption: both output and hours fall, inducing a fall in PPI inflation. The risk-sharing condition induces a depreciation of the real exchange rate, which combined with the decrease in PPI inflation leads to CPI inflation dropping dramatically. However, intermediate terms of trade deteriorates (ρ_t increases). Indeed, the dynamics of intermediate terms of trade, such as depicted in Table 1, depends on final terms of trade and also on (PPI converted) relative wages. The combined fall in domestic consumption and hours leads wages to shrink, increasing the competitiveness of domestic intermediate goods. When $\gamma = 0$, it does not affect the domestic economy. However, when $\gamma > 0$, it tends to increase intermediate exports and thereby reduces the fall in hours. While domestic hours fall less, so do wages and the magnitude of the deterioration in intermediate goods terms of trade (the increase in ρ_t) is lower. Consequently, the dynamics of both PPI and CPI inflation is affected. Since CPI inflation falls less, the endogenous reduction of the nominal interest rate implied by the monetary policy rule is lower and monetary policy becomes tighter. As a consequence, consumption drops more and final terms of trade, through the

Figure 3
Impulse responses to a domestic monetary policy shock

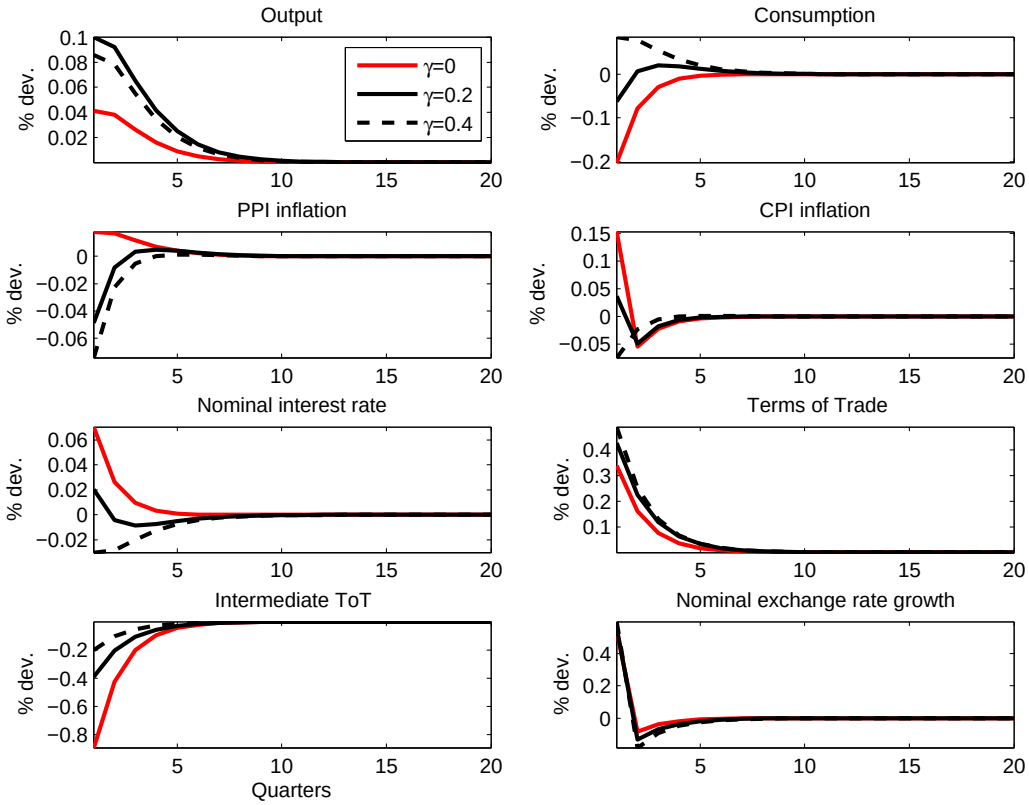


risk-sharing condition, improves more (s_t falls more). Overall, trade in intermediate goods does not substantially alter the effects of a domestic monetary policy shock.

Foreign monetary policy shock Figure 4 displays the IRFs of key variables to a unit foreign monetary policy shock. In the case of a foreign monetary policy shock, trade in intermediate goods has important consequences on the international transmission of the shock to the small open economy.

When $\gamma = 0$, the tightening in the foreign monetary policy leads to a depreciation of the nominal exchange rate. As a result, the trade balance improves and output increases. Consumption, however, falls. Firms, facing a higher foreign demand, increase their labour demand, which results in higher wages. This causes an increase in the marginal cost of final goods producers and in-

Figure 4
Impulse responses to a foreign monetary policy shock



duces PPI inflation to increase. As final goods terms of trade depreciate, imported inflation leads to an increase in CPI inflation. The domestic central bank responds by increasing its nominal interest rate which, in turn, leads to a drop in domestic consumption. While foreign wages drop along with foreign hours, foreign output and foreign inflation, intermediate terms of trade improves, with however, no consequence on the domestic economy since $\gamma = 0$.

When $\gamma > 0$, this improvement in intermediate terms of trade (ρ_t decreases) induces a drop in the marginal production cost of final goods producers, as they substitute foreign inputs to domestic inputs. This tends to magnify the increase in domestic output and lowers the increase in the domestic CPI inflation rate or even changes the sign of the CPI inflation rate response (from positive to negative). As the domestic central bank targets the CPI inflation

rate, the response of the nominal interest rate is also directly affected which in turn, amplifies the response of consumption. Finally, the magnitude of the improvement of intermediate goods terms of trade is reduced since domestic hours increase less, reducing the required increase in domestic wages. Overall, incorporating trade in intermediate goods has important consequences on the international transmission pattern of foreign shocks to small open economies' macroeconomic dynamics.

6 Business cycles properties

In this section we investigate the cyclical properties of the model and compare them with the case where $\gamma = 0$. We also report the results when the central bank reacts to the PPI inflation rate instead of the CPI. We focus on several dimensions of the data that standard models have difficulties to account for, and summarize our results in Table 3. First, we report the share of variance explained by (both productivity and monetary policy) foreign shocks. Second, we display the exchange rate pass-through, i.e. $corr\left(\pi_t, \Delta e_t\right)$, which is usually much higher in standard models' predictions than in the data (see McCallum and Nelson (2000)). Third, we report the correlation between domestic and foreign output, and compare it with the correlation between domestic and foreign consumption. Most international business cycles models are unable to reproduce the high international correlation of output observed in data, and rely on exogenous transmission mechanisms, such as the correlation of innovations or productivity spillovers, to match with empirical evidence.

Under the CPI inflation targeting monetary policy rule the standard model ($\gamma = 0$) implies that only a small part of fluctuations in domestic variables are due to foreign disturbances. While the share is 1.02% and 2.37% for output and PPI inflation respectively, it is around 10% for CPI inflation and the nominal interest rate. Due to our assumption of complete financial markets, almost half of the variation in consumption is due to foreign shocks.[6] Table 3 shows that intermediate input trade increases the share of foreign shocks in the variance decomposition by several orders of magnitude. For example, when $\gamma = 0.2$, the variability due to the foreign shock is 16 times larger for output and 12 times larger for PPI inflation. For CPI inflation and the nominal interest rate, the share almost triples. When trade occurs solely at the intermediate goods level ($\gamma = 0.4$), foreign shocks account for more than

[6] We relax this assumption in the next section.

Table 3. Business cycles properties

	CPI inflation targeting			PPI inflation targeting		
	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$
Share of for. shocks in VD						
Output	1.02	16.35	56.14	0.82	14.16	56.14
Consumption	54.32	52.51	56.14	50.45	50.16	56.14
PPI inflation	2.37	24.88	64.66	0.06	22.53	64.66
CPI inflation	10.14	30.27	64.66	14.67	29.20	64.66
Nominal interest rate	11.36	32.19	52.89	0.33	19.82	52.89
Exchange rate pass-through						
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_t\right)$	0.67	0.39	0.01	0.74	0.44	0.01
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-1}\right)$	0.21	0.06	0.01	0.26	0.07	0.01
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-2}\right)$	0.20	0.07	0.00	0.27	0.09	0.00
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-3}\right)$	0.18	0.07	-0.00	0.26	0.09	-0.00
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-4}\right)$	0.17	0.06	-0.01	0.24	0.08	-0.01
International correlations						
$corr\left(\widehat{y}_t, \widehat{y}_t^*\right)$	-0.05	0.35	0.70	-0.09	0.32	0.70
$corr\left(\widehat{c}_t, \widehat{c}_t^*\right)$	0.73	0.71	0.70	0.71	0.69	0.70

Note: International variables (terms of trade, exchange rates) are not reported in the variance decomposition since the share of foreign shocks in their variance is, by construction, 50%.

half of the variation for all the domestic variables Note that in this case, there is no distinction between consumer and producer price inflation and domestic output is equal to domestic consumption.

When the central bank targets the PPI inflation rate, the share of variance attributed to foreign shocks is smaller in the absence of intermediate trade compared to the CPI inflation targeting case. Indeed, when the central bank targets the CPI inflation rate, the response of the nominal interest rate incorporates some of the fluctuations of consumption goods terms of trade, increasing the pass-through of foreign shocks to domestic variables. On the contrary, the fluctuations of terms of trade are not incorporated when the central bank targets the PPI inflation rate. As a result, the proportional increase of the contribution of foreign shocks to domestic variables variability is much higher under PPI inflation targeting. Again, due to the fact that CPI and PPI are equal when $\gamma = 0.4$, the results are identical under both monetary policy rules.

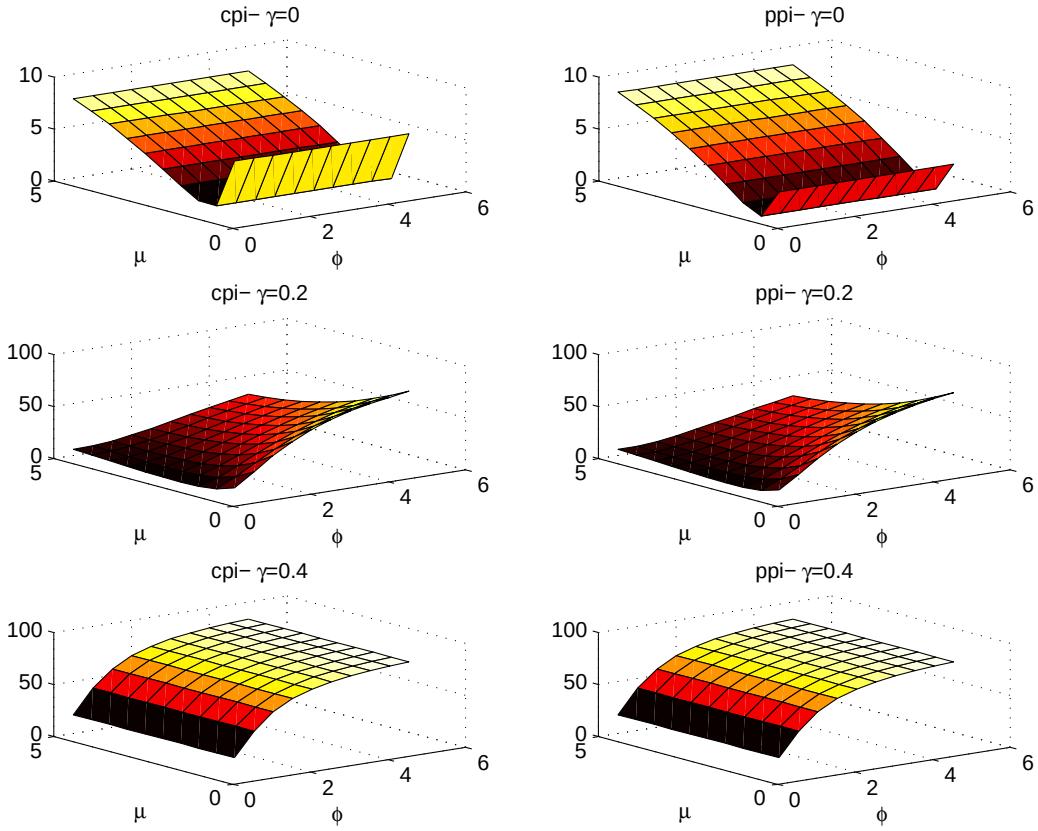
Overall, our results suggest that considering trade linkages at the production level is important to account for the substantial role of foreign shocks in the business cycles of small open economies, as documented in empirical studies.

We now turn to the implications of our model in terms of exchange rate

pass-through. McCallum and Nelson (2000) argue that the standard open economy New Keynesian model is unable to deliver the low exchange rate pass-through observed in the data (defined as the correlation between nominal exchange rate depreciation and CPI inflation). They argue that a model in which trade occurs solely at the intermediate goods level can generate a low exchange rate pass-through in line with the data. Our model encompasses their model as a special case. Indeed, when $\gamma = 0.4$ ($\alpha = 0$) and $\phi = 1$, all trade in our model occurs at the intermediate goods level and the production function is a Cobb-Douglas in foreign and domestic intermediate inputs as in McCallum and Nelson (2000). The middle part of Table 3 reports the pass-through at different time horizons under alternative calibrations of intermediate trade openness and monetary policy specifications. The contemporaneous correlation between inflation and nominal exchange rate depreciation is much lower and is decreasing with the share of intermediate goods trade. This result holds independently of the monetary policy inflation target. In accordance with the results of McCallum and Nelson (2000), the correlation is close to zero when $\gamma = 0.4$. When $\gamma = 0.2$, the cross correlation drops to low values much faster than the standard model: the correlation remains around 0.2 even after 4 quarters. Again, these results are even more self-evident when the central bank targets the PPI inflation rate. Under this rule, as the central bank does not react to exchange variations, the degree of pass-through is higher under all specifications.

Finally, Table 3 contrasts the impact of trade in intermediate goods on the international correlation of output. In all cases, the international correlation of consumption is very high, mostly due to financial markets completeness (above 0.7). When $\gamma = 0$, as predicted by most open economy models (see Backus, Kehoe, and Kydland (1993) for instance), the correlation between domestic and foreign output is negative and close to zero, as made clear by IRFs in the previous section. As γ increases, while the correlation of consumptions remains high, the correlation of outputs increases because of the extra trade linkage, inducing domestic output to be sensitive to variations of intermediate goods terms of trade. In the extreme case where $\gamma = 0.4$, international correlations of consumption and output are equal since in this case all imports occur at the production stage, and thus aggregate domestic consumption equals domestic output. As in Huang and Liu (2007), our results prove that trade in intermediate goods and international production linkages may help resolving the so-called output-consumption anomaly.

Figure 5
Share of foreign shocks in the variance decomposition of output, as a function of μ and ϕ.



7 Sensitivity analysis

In this section, we check the robustness of our results to changes in trade elasticities (μ and ϕ), intertemporal elasticity of substitution (σ) and labour supply elasticity (ψ). We choose to focus on the variance decomposition of output.

Figure 5 shows the share of foreign shocks in the variance decomposition of output as a function of μ and ϕ under various values of trade openness in intermediate goods and for alternative monetary policy targets (CPI vs PPI).

The first row of Figure 5 presents the results under the standard model, in which the elasticity of substitution between intermediate goods (ϕ) has no

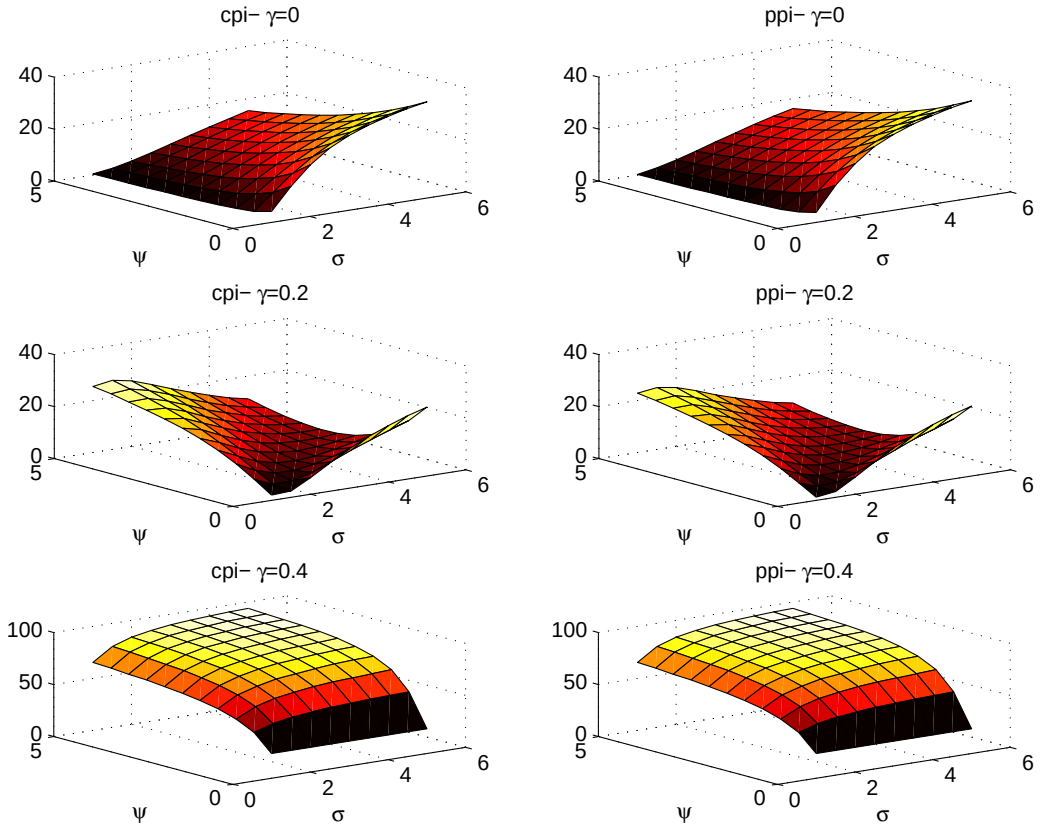
impact on the dynamics of the model. The two graphs show that, under complete markets, the share of foreign shocks in the variance of output is increasing with the elasticity of substitution between domestic and foreign final goods (μ). It is the case since higher values of μ magnify the transmission of real exchange rate fluctuations to the domestic economy, through the standard expenditure switching effect. However, although increasing, the share of foreign shocks remains extremely low for all values of μ. Alternatively, when $\gamma = 0.4$, all trade occurs at the production stage and the share of output explained by foreign shocks is completely independent from variations in μ. In this case, the share of foreign shocks are monotonically increasing with ϕ. For large values of ϕ, our model implies that more than half of the variability in output is attributed to foreign shocks. When $\gamma = \alpha = 0.2$, a higher elasticity of substitution between domestic and foreign intermediate input (ϕ) increases unambiguously the share of output variance explained by foreign shocks. Although, the amplification is much larger for low values of elasticity of substitution between consumption goods.

Second, Figure 6 shows the share of foreign shocks in the variance of output, as a function of σ and ψ under various values of trade openness in intermediate goods and for alternative monetary policy targets (CPI vs PPI).

In Figure 6, we let σ vary between 1 and 5 and ψ vary between 0 and 5. Our results are again robust to the specification of monetary policy. The value of γ, on the other hand, plays a key role.

When $\gamma = 0$ (and $\alpha = 0.4$), an increase in the Frisch elasticity (a drop in the value of ψ) magnifies the share of foreign shocks in the variance decomposition of output. This is due to the terms of trade spillover on labour supply, such as documented by Corsetti and Pesenti (2001). When hours are more responsive to changes in wages (when ψ drops), final goods terms of trade fluctuations affects the CPI-deflated real wage that has in turn a higher impact on domestic hours worked. Thereby the impact of variations of final goods terms of trade on domestic output is larger and the share of foreign shocks in the variance of output increases. On the other hand, an increase in the risk-aversion parameter (σ) favors a better transmission of foreign shocks to the domestic output. Indeed, the risk-sharing condition ($\widehat{c}_t = \widehat{c}_t^* + \frac{1}{\sigma}\widehat{q}_t$) implies that the effects of exchange rate movements are reduced with higher values of σ. It increases the share attributed to the shocks affecting foreign consumption in the dynamics of domestic consumption, which in turn affects domestic output.

Figure 6
Share of foreign shocks in the variance decomposition of output, as a function of σ and ψ



When $\gamma = 0.2$ (and $\alpha = 0.2$), we observe two competing effects: the final goods terms of trade spillover and the intermediate goods terms of trade spillover. When risk-aversion (σ) is high, the risk-sharing condition implies a much higher volatility of final terms of trade relative to the volatility of intermediate goods terms of trade. Therefore the final terms of trade spillover dominates and a decrease in labour supply elasticity lowers the share of output variance due to foreign shocks. On the other hand, when σ is low, the volatility of final goods terms of trade is lower relative to that of intermediate goods terms of trade. In this case, a decrease in labour supply elasticity amplifies the volatility of intermediate goods terms of trade, which translates to output fluctuations through production-level expenditure switching. Therefore, the share of foreign shocks in the variance of output increases alongside with a fall in labour supply elasticity.

Finally, when all trade occurs at the production stage, the share of foreign shocks remains high for all values of σ and ψ, although large values of these parameters magnify further the share of output variance due to foreign shocks. In this case, the intermediate goods terms of trade spillover is the only mechanism at work.

8 An extension with incomplete financial markets

We further investigate the properties of a similar model where international financial markets are incomplete. While households previously had access to a full portfolio of state-contingent assets, they are now left with two assets only: a domestic and an international bond. We assume that trading the international bond requires the payment of quadratic costs to (virtual) financial intermediaries, following Schmitt-Grohé and Uribe (2003). As a consequence, the risk-sharing condition does not hold and net foreign assets impact the dynamics of relative consumptions. The uncovered interest rate parity is modified:[7]

$$E_t \left\{ \Delta \widehat{\varepsilon}_{t+1} \right\} = \widehat{r}_t - \widehat{r}_t^* + \chi \widehat{b}_t \tag{7}$$

where χ is a parameter governing adjustment costs and $\widehat{b}_t = \frac{b_t - b}{y}$ is the deviation of net foreign assets (as a percentage of steady state output) from their steady state level. We simplify the analysis by assuming zero initial net foreign assets, i.e. $b = 0$. According to Equation (7), relative returns attached to domestic bonds increase (decrease) when net foreign assets are positive (negative) to give households an incentive to reallocate their portfolios in favor of domestic (international) bonds. Furthermore, the dynamics of net foreign assets are given by[8]

$$\widehat{b}_t - \beta^{-1} \widehat{b}_{t-1} = \gamma \left((\widehat{y}_t^* - \widehat{y}_t) + \sigma_\rho \widehat{\rho}_t \right) + \alpha \left((\widehat{c}_t^* - \widehat{c}_t) + \sigma_s \widehat{s}_t \right)$$

where $\sigma_\rho = \phi \left(1 + (1 - \gamma)\right) - 1$ and $\sigma_s = \mu \left(1 + (1 - \alpha)\right) - 1$. The accumulation of net foreign assets depends on the trade balance, that can be split into final goods and intermediate goods trade balances.

[7] Microfoundations of these relations are available upon request and follow closely Benigno (2009).

[8] Assuming that domestic bonds are in zero net supply, the dynamics of net foreign assets are obtained by aggregating all constraints and making use of the market clearing conditions of final and intermediate goods markets.

Table 4. The log-linearized model with incomplete financial markets

Euler equations

$$\sigma E_t\left\{\widehat{c}_{t+1}\right\}-\sigma\widehat{c}_t=\widehat{r}_t-E_t\left\{\widehat{\pi}_{h,t+1}+\alpha\Delta\widehat{s}_{t+1}\right\}$$

$$\sigma E_t\left\{\widehat{c}^*_{t+1}\right\}-\sigma\widehat{c}^*_t=\widehat{r}^*_t-E_t\left\{\widehat{\pi}^*_{f,t+1}\right\}$$

NK Phillips curves

$$\widehat{\pi}_{h,t}=\beta E_t\left\{\widehat{\pi}_{h,t+1}\right\}+\frac{(1-\eta\beta)(1-\eta)}{\eta}\left(\psi\widehat{n}_t+\sigma\widehat{c}_t-\widehat{a}_t+\alpha\widehat{s}_t+\gamma\widehat{\rho}_t\right)$$

$$\widehat{\pi}^*_{f,t}=\beta E_t\left\{\widehat{\pi}^*_{f,t+1}\right\}+\frac{(1-\eta\beta)(1-\eta)}{\eta}\left(\psi\widehat{n}^*_t+\sigma\widehat{c}^*_t-\widehat{a}^*_t\right)$$

Consumption goods market clearing

$$\widehat{y}_t=(1-\alpha)\,\widehat{c}_t+\alpha\widehat{c}^*_t+\mu\alpha\left(1+(1-\alpha)\right)\widehat{s}_t$$

$$\widehat{y}^*_t=\widehat{c}^*_t$$

Intermediate goods market clearing

$$\widehat{a}_t+\widehat{n}_t=(1-\gamma)\,\widehat{y}_t+\gamma\widehat{y}^*_t+\phi\gamma\left(1+(1-\gamma)\right)\widehat{\rho}_t$$

$$\widehat{a}^*_t+\widehat{n}^*_t=\widehat{y}^*_t$$

Terms of trade, exchange rates and net foreign assets

$$\widehat{\rho}_t=(1-\alpha)\,\widehat{s}_t+\psi\left(\widehat{n}^*_t-\widehat{n}_t\right)+\sigma\left(\widehat{c}^*_t-\widehat{c}_t\right)-\left(\widehat{a}^*_t-\widehat{a}_t\right)$$

$$\widehat{q}_t=(1-\alpha)\,\widehat{s}_t$$

$$\Delta\widehat{s}_t=\Delta\widehat{\varepsilon}_t+\widehat{\pi}^*_{f,t}-\widehat{\pi}_{h,t}$$

$$E_t\left\{\Delta\widehat{\varepsilon}_{t+1}\right\}=\widehat{r}_t-\widehat{r}^*_t+\chi\widehat{b}_t$$

$$\widehat{b}_t-\beta^{-1}\widehat{b}_{t-1}=\gamma\left(\left(\widehat{y}^*_t-\widehat{y}_t\right)+\sigma_\rho\widehat{\rho}_t\right)+\alpha\left(\left(\widehat{c}^*_t-\widehat{c}_t\right)+\sigma_s\widehat{s}_t\right)$$

where $\sigma_\rho=\phi\left(1+(1-\gamma)\right)-1$ and $\sigma_s=\mu\left(1+(1-\alpha)\right)-1$

Exogenous shocks

$$\widehat{a}_t=\rho_a\widehat{a}_{t-1}+\xi_{a,t}$$

$$\widehat{a}^*_t=\rho_{a^*}\widehat{a}^*_{t-1}+\xi_{a^*,t}$$

In addition, as the risk-sharing condition does not hold anymore, the foreign Euler equation is now important in determining the equilibrium. Finally, the market clearing condition for final goods is modified. The full model with incomplete financial markets is detailed in Table 4 and closed with the monetary policy specifications described in Section 4.

Table 5 reports the same business cycle statistics (share of foreign shocks in variance decomposition, exchange rate pass-through and international correlations) when financial markets are incomplete.

Our results are qualitatively robust to the introduction of incomplete financial markets. The share of variance explained by foreign shocks remains an increasing function of the share of intermediate trade in total trade. The model also delivers the same conclusion that trade in intermediate goods lowers the exchange rate pass-through. However, the increase in the share

Table 5. Business cycles properties with incomplete financial markets

	CPI inflation targeting			PPI inflation targeting		
	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$
Share of for. shocks in VD						
Output	1.41	8.00	29.27	1.53	6.90	29.27
Consumption	47.17	33.95	29.27	44.14	32.44	29.27
PPI inflation	2.29	16.52	40.27	0.23	14.89	40.27
CPI inflation	9.35	20.03	40.27	12.03	19.40	40.27
Nominal interest rate	11.98	21.67	31.20	1.06	13.36	31.20
Exchange rate pass-through						
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_t\right)$	0.68	0.45	0.14	0.73	0.48	0.14
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-1}\right)$	0.22	0.14	0.15	0.27	0.15	0.15
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-2}\right)$	0.21	0.15	0.14	0.28	0.17	0.14
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-3}\right)$	0.19	0.14	0.14	0.26	0.16	0.14
$corr\left(\widehat{\pi}_t, \Delta\widehat{e}_{t-4}\right)$	0.17	0.14	0.13	0.24	0.16	0.13
International correlations						
$corr\left(\widehat{y}_t, \widehat{y}_t^*\right)$	-0.08	0.19	0.45	-0.11	0.17	0.45
$corr\left(\widehat{c}_t, \widehat{c}_t^*\right)$	0.67	0.54	0.45	0.65	0.53	0.45

Note: international variables (terms of trade, exchange rates) are not reported in the variance decomposition since the share of foreign shocks in their variance is, by construction, 50%.

of variance explained by foreign shocks is quantitatively less important. This is the case since incompleteness of financial markets lowers the volatility of both final goods and intermediate terms of trade, which in turn implies that the transmission of movements in these terms of trade to domestic variables is lower. In terms of exchange rate pass-through, the decrease is less sharp for comparable shares of trade in intermediate goods in total trade. Finally, incomplete financial markets do not change our conclusions in terms of international correlations but reduces the correlation of both consumptions and outputs.

9 Conclusion

In this paper, we show that incorporating trade in intermediate goods, or equivalently internationalised production, in an otherwise standard new-Keynesian small open economy model has important consequences for business cycle dynamics. We document an additional channel through which external shocks and exchange rate fluctuations impact the economy, we call this the "cost channel": changes in relative prices or the nominal exchange rate affect trade of intermediate goods and the marginal production cost of consumption goods producers through the price of imported inputs. We show that this additional channel results in a dramatic increase in the share

of foreign shocks in the variance decomposition of domestic variables. While taking into account intermediate input trade can also bring the standard model in line with the empirical evidence with regards to the exchange rate pass-through. Finally, trade in intermediate goods increases the international correlations of output but does not completely solve the output-consumption anomaly. Future research may explore the implications of trade in intermediate goods for the optimal conduct of monetary policy. It also may assess the extent to which taking into account intermediate goods trade can improve the empirical fit of an estimated small open economy model.

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