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Macroeconomic Volatility and Exchange Rate Pass-through under Internationalized Production

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Abstract

This paper shows that internationalized production, modelled as trade in intermediate goods, challenges the standard result according to which exchange rate volatility insulates small open economies from external shocks. Movements of relative prices affect the economy through an additional channel, denoted as the cost channel. We show that this channel also acts as an automatic stabilizer and that macroeconomic volatility is dramatically reduced when trade in intermediate goods is taken into account. Finally, trade in intermediate goods affects the exchange rate pass-through to consumption prices and may contribute explaining the puzzle described by McCallum & Nelson (2000).

Keywords: Small open economy, internationalized production, macroeconomic volatility, exchange rate pass-through.

1 Introduction

Recently the New Keynesian synthesis models have been extensively applied to the study of monetary policy in a small open economy framework.¹ Most of these models assume that the traded good is a consumption good. However, little attention has been devoted to the role of imported producer inputs. This paper fills this gap by analyzing

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

the role of intermediate goods trade within a dynamic stochastic general equilibrium model of a small open economy with imperfect competition and nominal rigidities.

The idea that exchange rate flexibility both insulates economies from external shocks and preserves the independence of monetary policy goes back to Friedman (1953). The recent revival of this idea is due to Galí & Monacelli (2005). Using a fully microfounded New Keynesian model, they demonstrate that a small open economy is fully insulated from external demand shocks under specific parametrizations, *i.e.* when both the risk-aversion parameter and the elasticity of substitution between domestic and foreign goods are unitary. In this case, monetary policy should thus be aimed at stabilizing domestic targets only, such as producer price inflation and the output gap, and exchange rate flexibility should be preserved. In the general case however, de Paoli (2009) shows that small open economies are not perfectly insulated from external shocks, with important consequences on monetary policy decisions.

In this paper, we develop a New Keynesian microfounded model of a small open economy with trade of both consumption and intermediate goods. The assumption of intermediate goods trade proves to have major consequences on the macroeconomic dynamics caused by standard shocks – such as productivity shocks and foreign demand shocks, and provides new insights concerning the insulating properties of exchange rate flexibility. In particular, even in the specific case considered by Galí & Monacelli (2005), which we treat as our benchmark, small open economies are never insulated from external shocks.

The assumption of intermediate goods trade receives an important and growing empirical support. For instance Feenstra (1998) and Hummels, Ishii & Yi (2001) show that the internationalization of production processes has dramatically increased over the last thirty years. Moreover, recent EMU 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

²Data available at <http://sdw.ecb.europa.eu/>.

Theoretically, Findlay & 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 stabilization 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.³ In most of these contributions, prices are pre-set and monetary aggregates are considered as the monetary policy instruments. In contrast, 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 latter approach has been used by Smets & Wouters (2002) or Batini, Harrison & Millard (2003), in which intermediate goods are modeled as differentiated imported goods. Importers buy an homogenous good, differentiate it and sell it to firms and consumers, selling prices being sticky. The introduction of price dispersion in the imported sector implies that optimal monetary policy should jointly target the inflation of production and imported prices. Finally, McCallum & Nelson (2000) consider a model in which imports are solely used in the production process together with domestic labor. International trade thus occurs only at the intermediate level and producer price inflation and consumer inflation are perfectly identical. They 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 & Monacelli (2005).

Our model takes an approach between the two extremes: we consider a model with both intermediate and consumption goods trade. Producer prices are flexible in the intermediate goods sector and Calvo staggered in the consumption goods sector.⁴ The intensity with which foreign imports are used in the production of consumption goods is governed by one parameter of the production function. Therefore, we can analyze

³See for example Cavallari (2004), Shi & Xu (2007), Devereux & Engel (2007).

⁴Assuming sticky prices in the intermediate goods sector would be the same as assuming sticky wages when shutting off the channel of trade of intermediate goods. We therefore assume flexible prices so as to be consistent with the model of Galí & Monacelli (2005), our benchmark.

the role of various levels of intermediate trade on business cycles properties of output, inflation and exchange rates. We document an additional channel through which movements of relative prices and exchange rates are passed through macroeconomic aggregates. As long as intermediate output can be sold internationally, movements in the exchange rate modify the demand addressed to the intermediate domestic firms. Since the price of intermediate goods determines the marginal cost of consumption goods producers and, *via* the Phillips Curve, inflation dynamics, the exchange rate has an effect on inflation and output through the additional channel, denoted as the “cost channel”.

We argue that this channel deeply affects business cycle properties and macroeconomic volatility in small open economies. Our main results are as follows:

- In contrast with Galí & Monacelli (2005), even when the elasticity of substitution among consumption goods and the risk–aversion parameter are both unitary, the economy is not insulated from external shocks when the nominal exchange rate is flexible.
- Macroeconomic volatility is dramatically reduced under standard monetary policy rules when taking intermediate goods trade into account. This trade structure appears to be a build–in automatic stabilization mechanism.
- The exchange rate pass–through is dramatically reduced and much more consistent with the data when trade occurs more intensively at the intermediate level.

The remainder of the paper is organized as follows. In section 2 we lay out the theoretical model. In Section 3 we present the steady state and derive a log–linearized version of the model. We qualitatively analyze model dynamics using a reduced form version. Section 4 proceeds to a quantitative evaluation of the model by analyzing impulse response function after domestic technology shocks and external (world) demand shocks. Section 5 also discusses the cyclical properties of the model by analyzing the second–order moments implied by our model. Section 6 concludes.

2 The model

Our model closely follows Galí & Monacelli (2005) except for the role of the intermediate goods sector. The world economy is formed by a continuum of small open economies. The optimality conditions characterizing 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,

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

subject to the budget constraint,

$$E_t \{ \ell_{t,t+1} b_{t+1} \} + p_{c,t} c_t = b_t + \chi_t + w_t n_t + tax_t, \quad (2)$$

and subject to the appropriate transversality condition. We note λ_t the multiplier associated with the budget constraint.

In (1), the parameter β is the subjective discount factor, c_t is the consumption bundle chosen by the representative household, n_t is the quantity of labour competitively supplied to the firms of country i . In (2), w_t is the nominal wage rate, $\chi_t = \int_0^1 \chi_t(j) dj$ is the profit paid by national final firms (indexed by j) to the representative household, b_t is the value of a portfolio of state contingent assets hold in period $t - 1$, $\ell_{t,t+1}$ is the stochastic discount factor for one-period ahead nominal payments attached to the portfolio, $p_{c,t}$ is the consumer price index. Finally, tax_t is a lump-sum transfer.

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

$$-\frac{u_{n,t}}{u_{c,t}} - \frac{w_t}{p_{c,t}} = 0, \quad (3)$$

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

Equation (3) is a standard open economy labor supply function, describing the intra-temporal 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 inflation and the return on the financial portfolio. Denoting $r_t = \frac{1}{E_t\{\ell_{t,t+1}\}}$ as the gross return on a riskless one-period bond, and taking conditional expectations on both sides of (4), the standard Euler equation writes

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

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

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

while the consumption of a representative household in the rest of the world is,

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

Given that the law of one price holds in this setting, companion consumption price indexes are,

$$p_{c,t} = \left[(1 - \alpha) (p_t)^{1-\mu} + \alpha (\varepsilon_t p_t^*)^{1-\mu} \right]^{\frac{1}{1-\mu}}, \quad p_{c,t}^* = \left[(1 - \alpha) (p_t^*)^{1-\mu} + \alpha (\varepsilon_t^{-1} p_t)^{1-\mu} \right]^{\frac{1}{1-\mu}}.$$

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 and where $1 - \alpha$ 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. We define terms-of-trade and the real exchange rate respectively as,⁵

$$s_t = \frac{\varepsilon_t p_t^*}{p_t}, \quad \text{and} \quad q_t = \frac{\varepsilon_t p_{c,t}^*}{p_{c,t}}.$$

⁵The definition of terms-of-trade is meant to be consistent with the definition of the real exchange rate.

The standard Dixit & Stiglitz (1977) consumption subindexes are,

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

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

where $c_{h,t}(j)$ (resp. $c_{h,t}^*(j)$) is the consumption of a typical final good j of the home country (resp. rest of the world) by the representative consumer and $\theta > 1$ is the elasticity of substitution between national varieties of final goods.

Accordingly, optimal variety demands addressed to domestic producers depend on relative prices of goods, of varieties and on the aggregate consumption,

$$c_{h,t}(j) = (1 - \alpha) \left[\frac{p_t}{p_{c,t}} \right]^{-\mu} \left[\frac{p_t(j)}{p_t} \right]^{-\theta} c_t, \quad c_{h,t}^*(j) = \alpha \left[\frac{\varepsilon_t^{-1} p_t}{p_{c,t}^*} \right]^{-\mu} \left[\frac{p_t(j)}{p_t} \right]^{-\theta} c_t^*,$$

where c_t^* evolves according to,

$$\log c_{t+1}^* = \rho_{c^*} \log c_t^* + \xi_{c^*,t+1}.$$

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

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

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

$$\frac{u_{c,t}^*}{u_{c,t}} = \epsilon \frac{\varepsilon_t p_{c,t}^*}{p_{c,t}} \quad (5)$$

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

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

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

$$x_t = a_t l_t, \quad x_t^* = \bar{a}^* l_t^*,$$

where,

$$\log a_{t+1} = \rho_a \log a_t + \xi_{a,t+1}.$$

These firms sell their products exactly at their nominal marginal production cost, respectively w_t/a_t and w_t^*/\bar{a}^* .

Both in the home economy and in the rest of the world, consumption goods producers operate on monopolistically competitive markets. Each producer is the single supplier of a variety combining domestic and foreign intermediate goods according to the following production function,

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

while the production function of foreign firms is,

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

In these expressions, $x_{h,t}(j)$ (resp. $x_{f,t}(j)$) is the quantity of intermediate goods produced in the home country (resp. in the rest of the world) demanded by consumption goods producers in the home country. $(1 - \gamma)$ 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 in Galí & Monacelli (2005), when $\gamma = 0$, the production function of domestic consumption goods producers and the associated marginal cost simply collapse to,

$$y_t(j) = a_t l_t(j),$$

$$mc_t = \frac{w_t}{a_t}.$$

This situation will be considered as our benchmark all along the paper. As long as $\gamma > 0$, consumption goods producers trade intermediate goods along the production process and the production is internationalized and the corresponding nominal marginal production costs are,

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

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

Optimal intermediate goods demands addressed to domestic producers are thus given by,

$$x_{h,t}(j) = (1 - \gamma) \left[\frac{w_t/a_t}{mc_t} \right]^{-\phi} y_t(j), \quad x_{h,t}^*(j) = \gamma \left[\frac{\varepsilon_t^{-1} w_t/a_t}{mc_t^*} \right]^{-\phi} y_t^*(j).$$

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

$$\bar{p}_t(j) = \varphi \frac{\sum_{v=0}^{\infty} (\eta\beta)^v E_t \{ \lambda_{t+v} y_{t+v}(j) mc_{t+v} \}}{\sum_{v=0}^{\infty} (\eta\beta)^v E_t \{ \lambda_{t+v} y_{t+v}(j) \}},$$

where, $y_t(j) = c_{h,t}(j) + c_{h,t}^*(j)$ is the aggregate demand addressed to firm j . In this expression, $\varphi = \frac{\theta}{(\theta-1)(1-\tau)}$ is the steady state mark-up signalling the distortion of the first-best allocation caused by monopolistic competition and τ is a constant tax/subsidy that might 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,

$$p_t = \left[(1 - \eta) \bar{p}_t(j)^{1-\theta} + \eta p_{t-1}^{1-\theta} \right]^{\frac{1}{1-\theta}}.$$

Equilibrium. We define the 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 $p_{c,t}^* \simeq p_t^*$. Consequently, using the definition of CPI, the definition of consumption goods terms-of-trade and making use of the risk-sharing condition, *i.e.* $\frac{u_{c,t}^*}{u_{c,t}} = q_t$, we can eliminate foreign consumption from the market clearing condition of domestically produced consumption goods,

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

By the same reasoning, the market clearing condition of domestically produced intermediate goods 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,

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

Finally, the labour markets clearing condition is,

$$n_t = l_t.$$

3 Dynamic properties

Preferences. In order to consider the dynamic properties of the model, we first specify the utility function of the households. We assume standard CRRA separable preferences,

$$u(c_t, n_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \frac{n_t^{1+\psi}}{1+\psi},$$

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

Steady state. In the steady state, $x_t = x, \forall x$. We focus on a symmetric steady state and assume $c^* = c$ so as 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 characterized by,

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

Log-linearization. We log-linearize the model around the steady state. A hat denotes the deviation of a variable from its steady state. The linearized equilibrium conditions are given in the appendix A. After some algebra, the dynamics of output and inflation can be represented by the following two dynamic equations:

$$\begin{aligned}\epsilon E_t \{\Delta \hat{y}_{t+1}\} &= \hat{r}_t - E_t \{\hat{\pi}_{t+1}\} - (\sigma - \epsilon) E_t \{\Delta \hat{y}_{t+1}^*\}, \\ \hat{\pi}_t &= \beta E_t \{\hat{\pi}_{t+1}\} + \kappa (\kappa_y \hat{y}_t + \kappa_{c^*} \hat{c}_t^* + \kappa_a \hat{a}_t),\end{aligned}$$

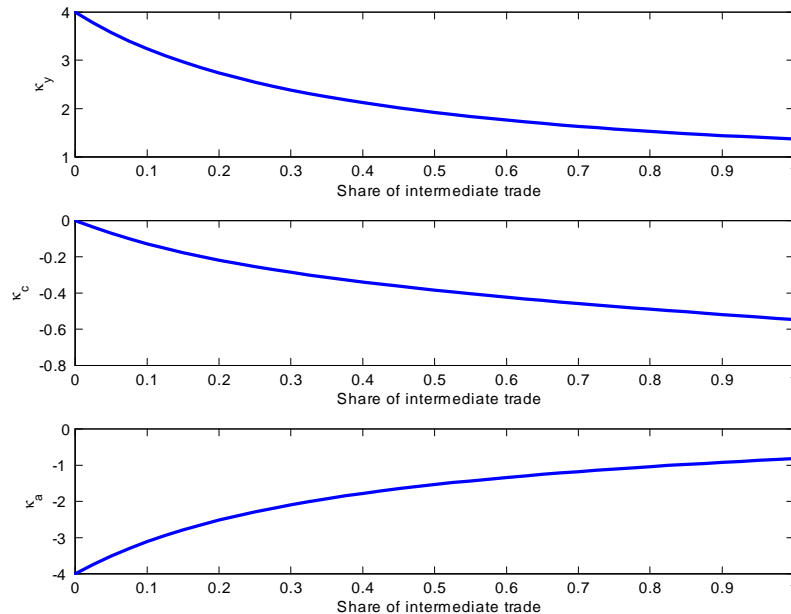
where the reduced form parameters are functions of structural parameters:

$$\begin{aligned}\epsilon &= \frac{\sigma}{(1 - \alpha)^2 + \sigma \mu \alpha (1 + (1 - \alpha))} > 0, & \kappa &= \frac{(1 - \eta \beta) (1 - \eta)}{\eta} \geq 0, \\ \varpi &= \phi \gamma (1 + (1 - \gamma)) \geq 0, & \kappa_y &= \epsilon + \frac{\psi (1 - \gamma)^2}{1 + \varpi \psi} > 0, \\ \kappa_{c^*} &= (\sigma (1 - \gamma) - \epsilon) + \frac{\psi (1 - \gamma) (\gamma - \varpi \sigma)}{1 + \varpi \psi} \leq 0, \\ \kappa_a &= \frac{\psi (1 - \gamma) (\varpi - 1)}{1 + \varpi \psi} - (1 - \gamma) < 0.\end{aligned}$$

Our model can be summarized with a dynamic IS equation and a New Keynesian Phillips Curve. The IS curve describes a negative relation between the real interest rate and output, *i.e.* an increase in the real interest rate implies an intertemporal substitution of private consumption that leads current consumption to drop. This adjustment scheme translates to output through the equilibrium of consumption goods markets. Inspecting the reduced forms parameters makes it clear that IS equation parameters are not affected by intermediate goods trade.

The New Keynesian Phillips Curve describes a positive transmission of output fluctuations to the inflation rate. The parameters governing the elasticity of inflation to output fluctuations, productivity and world demand shocks are some complicated function of γ our measure of intermediate trade intensity. However, it is clear that $\kappa_a < 0$: positive productivity shocks imply a reduction in the marginal cost, that impact negatively inflation dynamics. World demand shocks have either no impact on inflation dynamics ($\kappa_{c^*} = 0$) in the benchmark case ($\sigma = \epsilon$ when $\gamma = 0$ in the special case

Figure 1: Phillips curve elasticities with respect to share of intermediate trade



$\sigma = \mu = 1$, as in Galí & Monacelli (2005)) or impact negatively on inflation dynamics when production is internationalized ($\kappa_{c^*} \leq 0$). In this case ($\gamma > 0$), an increase in world demand implies a drop in the real exchange rate and intermediate goods terms-of-trade appreciate (ρ_t decreases), with two consequences. First, the competitiveness of domestic intermediate goods producers decreases. Second, domestic final goods producers are able to buy intermediate goods cheaper from the rest of the world. The first point results in a decrease in domestic exports of intermediate goods, requiring a decrease in the domestic real wage. The second point results in a direct reduction in the marginal cost of domestic consumption goods producers. As both effects are combined, the marginal cost is clearly reduced, which implies that inflation drops after a world demand shock.

To consider more precisely the effects of intermediate goods trade, we plot κ_y , κ_a and κ_{c^*} for different values of γ .⁶ Figure 1 shows that the elasticity of inflation to output, κ_y is monotonically decreasing in γ .

⁶The underlying calibration for other parameters is presented in the next section.

One can also observe that, with the baseline calibration, κ_c is equal to 0 as long as there is no trade of intermediate goods. The inflation rate in the domestic economy is therefore insulated from external shocks, as in Galí & Monacelli (2005). When the production is internationalized ($\gamma > 0$), κ_{c^*} is negative and decreasing alongside with the share of intermediate imports in total imports.

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

$$\widehat{r}_t = \rho_\pi \widehat{\pi}_t.$$

Parametrization. Our parametrization closely follows that of Galí & Monacelli (2005). We assume $\beta = 0.99$. We adopt a log-utility function in consumption by setting $\sigma = 1$. The parameter governing the disutility from labor, ψ , is set to 3, implying that labor supply elasticity is 1/3. We set, μ , the elasticity of substitution between domestic and foreign goods in the consumption bundle to unity. In the intermediate sector production function, we assume that $\phi = 1$. 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 internationalized, $\alpha = 0.4$. When we account for intermediate goods trade – when γ is positive, we adjust α to keep the share of total imports in output constant. In our baseline model with internationalized production, we assume that half of the imports are intermediate goods imports, *i.e.* $\alpha = \gamma = 0.2$. Data suggest that the average duration of prices of is about 4 quarters. We therefore set the price rigidity parameter to $\eta = 0.75$. Concerning the monetary policy rule, the elasticity of the nominal interest rate to the inflation rate is set to $\varphi_\pi = 1.5$. Finally, consistently with Galí & Monacelli (2005), parameters governing shocks processes are $\rho_a = 0.66$ and $\rho_{c^*} = 0.86$, $\sigma(\xi_a) = 0.0071$, $\sigma(\xi_{c^*}) = 0.0078$, and $corr(\xi_a, \xi_{c^*}) = 0.3$.

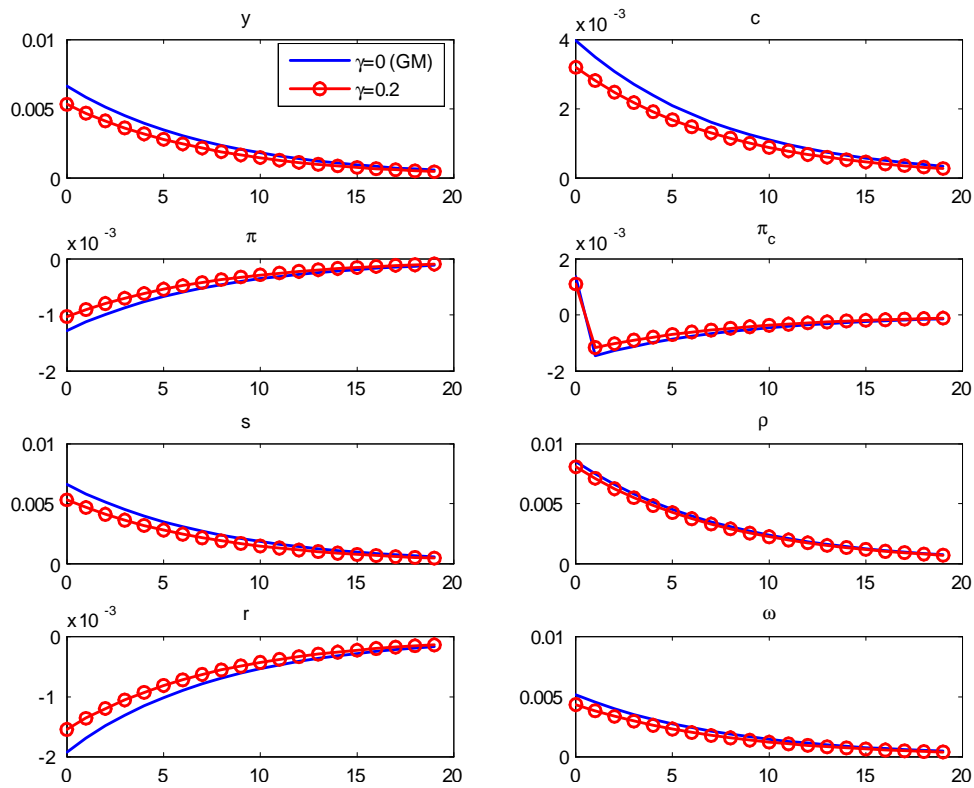
4 Impulse Response Functions

In this section, we analyze the dynamic response of our model economy in response to domestic technology shocks and world demand shocks. We report the Impulse

Response Functions (IRFs) of the model in the benchmark case ($\gamma = 0$) and with trade in intermediate goods ($\gamma = 0.2$).

Technology shocks. Figure 2 displays the impulse responses to a unit technology shock in both models under domestic inflation targeting. In both cases, the dynamic responses of the variables are qualitatively similar. A positive technology shock is associated with an increase in output and consumption alongside with a fall in inflation. 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 exchange rate since we assume that world interest rate is constant.

Figure 2: IRFs to a domestic technology shock.



The responses differ, however, quantitatively. When $\gamma = 0$, the effect of productivity shocks in 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. Beside the direct marginal cost effect, when $\gamma > 0$, our model displays an additional channel through which inflation dynamics are affected, originated from the depreciation of the nominal exchange rate.

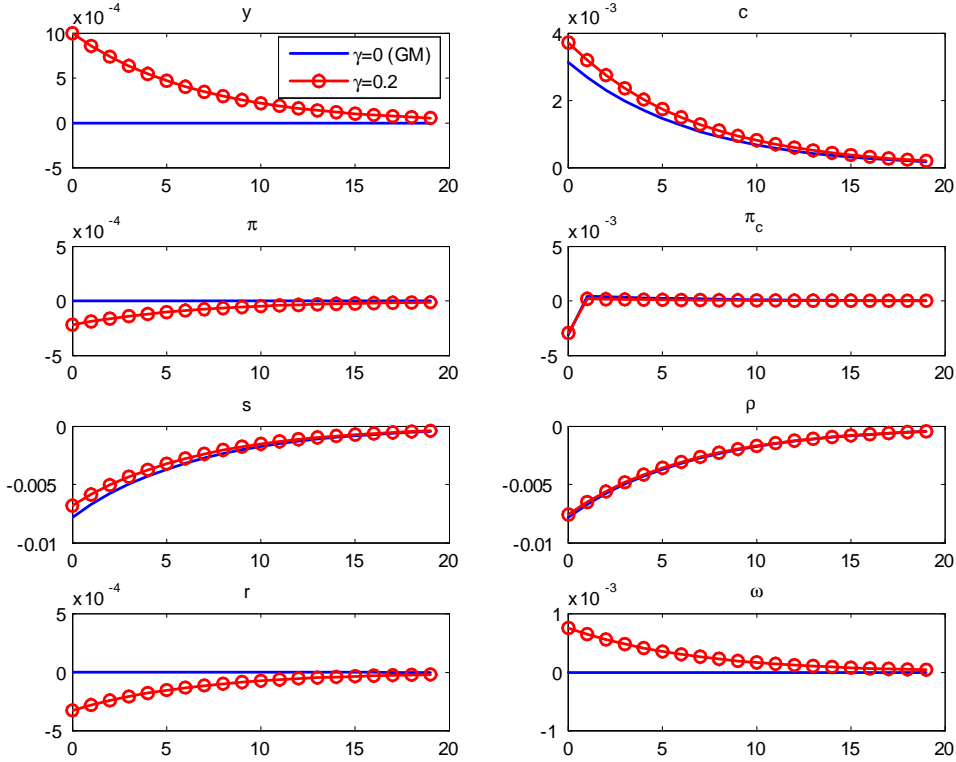
The deterioration of the terms-of-trade in the intermediate goods sector (ρ_t increases) makes the foreign intermediate goods more costly to acquire from the perspective of domestic firms. Hence, the fall in marginal cost is balanced by more expensive foreign intermediate goods. The lower reaction of marginal cost reduces the size of adjustment in inflation and in all other variables. This second round effect is absent in the benchmark model of Galí & Monacelli (2005) model, *i.e.* when $\gamma = 0$, since the marginal cost is insulated from external shocks (when $\sigma = \mu = 1$). For example, in response to the same technology shock the boost in output under internationalized production is two third of the increase in output documented by Galí & Monacelli (2005).

World demand shocks. Figure 3 reports the effect of a world demand shock.

First, in the benchmark case ($\gamma = 0$), a world demand shock has no effect on the domestic output and on the domestic PPI inflation rate. The demand shock, through the risk-sharing condition, implies a drop in the real exchange rate and an increase in consumption goods terms-of-trade (s_t decreases), that induces domestic consumption to increase. The world demand shock is also associated with an increase in the intermediate goods terms-of-trade (ρ_t), with no effect on intermediate goods markets. The real marginal cost of domestic firms is unchanged, which implies that inflation remains flat. Finally, the drop of the real exchange rate damages the competitiveness of domestic firms, which deteriorates the trade balance sufficiently to compensate the increase in domestic consumption. As a consequence, the domestic output and inflation rate are insulated from external shocks.

As long as $\gamma > 0$, fluctuations of the intermediate goods terms-of-trade now trigger intermediate goods trade flows and affect the real marginal cost of domestic consumption goods producers. The increase in the intermediate goods terms-of-trade (i) de-

Figure 3: IRFs to a world demand shock.



increases the competitiveness of domestic intermediate goods producers and (ii) makes it less costly for domestic final goods producers to buy intermediate goods from the rest of the world. The first point results in a decrease in intermediate goods exports, requiring a decrease in the domestic real wage. Even when the utility function is log in consumption and the elasticity of substitution between domestic and foreign goods is equal to unity, *i.e.* $\sigma = \mu = 1$, the domestic marginal cost, and hence domestic output and producer inflation, are not insulated from external shocks. Our model yields a positive effect of world demand shock on output and a decrease in inflation. Again the appreciation of terms-of-trade makes the foreign input cheaper – given that the world wage is assumed to be constant, and yields a decrease in the marginal cost moving inflation down.

5 Cyclical properties

This section inspects carefully the cyclical properties of our model and compares them with those implied by the model of Galí & Monacelli (2005). In addition to the standard model where the monetary policy rule reacts to the PPI inflation rate (domestic inflation-based Taylor rule, DITR for short), we also investigate several results attached to a model where the monetary policy rule responds to the CPI inflation rate (CPI inflation-based Taylor rule, CITR for short). Thus, Table 1 reports the volatility of domestic output, nominal exchange rate, PPI and CPI inflation rates, consumption goods terms-of-trade and intermediate goods terms-of-trade for both monetary policy rules and for alternative values of γ .

Table 1. Cyclical Properties: Standard Deviations (%)

	DITR		CITR	
	$\gamma = 0.2$	$\gamma = 0$ (GM)	$\gamma = 0.2$	$\gamma = 0$ (GM)
Output (\hat{y}_t)	0.42	0.56	0.47	0.59
Domestic Inflation ($\hat{\pi}_t$)	0.15	0.23	0.15	0.21
CPI Inflation ($\hat{\pi}_{c,t}$)	0.20	0.37	0.18	0.21
Cons. goods ToT (\hat{s}_t)	0.79	0.99	0.74	0.86
Intern. goods ToT ($\hat{\rho}_t$)	1.25	1.53	1.30	2.02
Nominal Depreciation ($\Delta\hat{e}_t$)	0.67	0.82	0.53	0.48

The first two columns present results when monetary policy targets domestic inflation rate. Consistently with our impulse response analysis, the volatility of all the variables are lower under internationalized production compared to the Galí & Monacelli (2005) model. Despite the fact that the economy is no more insulated from external shocks, the decrease in the volatility coming from technology and world demand shocks makes all variables less volatile.

Further, we look at the claim that allowing intermediate goods trade provides a better description of the correlation between inflation and exchange rate variations. In particular, McCallum & Nelson (2000) claim that the Galí & Monacelli (2005) model is unable to deliver the low exchange rate pass-through observed in the data. Indeed, in the data, according to McCallum & Nelson (2000), exchange rate pass-through,

measured as the correlation between nominal exchange rate variations and the CPI inflation rate ranges from almost zero to 0.5, depending on estimation periods and data frequency (quarterly or annual), while the exchange rate pass-through is around 0.9 in Galí & Monacelli (2005). Table 2 shows that the contemporaneous correlation between inflation and exchange rate depreciation is lower in our model.

Table 2. Exchange rate pass-through ($\pi_t^c, \Delta e_{t-k}$)

k	DITR		CITR	
	$\gamma = 0.2$	$\gamma = 0$ (GM)	$\gamma = 0.2$	$\gamma = 0$ (GM)
0	0.82	0.93	0.77	0.81
1	0.08	0.11	0.18	0.30
2	-0.01	0.02	-0.02	0.06
3	-0.05	-0.03	-0.01	-0.06
4	-0.08	-0.06	-0.13	-0.12

The decrease of the correlation between inflation and lagged exchange rate is somewhat more rapid in the Galí & Monacelli (2005) model under domestic inflation targeting. Of course, the contemporaneous correlation decreases when the share of intermediate imports in total imports is higher, as depicted in the next table. Indeed, Table 3 indicates that the share of intermediate goods imports in total imports negatively affects the correlation between inflation and exchange rate. This is again due to the counter-balancing effect of exchange rate movements on the marginal cost under internationalized production.

Table 3. Exchange rate PT ($\pi_t^c, \Delta e_t$)

γ	0	0.1	0.2	0.3	0.4
DITR	0.93	0.89	0.82	0.67	0.42
CITR	0.81	0.81	0.77	0.66	0.42

In the benchmark case ($\gamma = 0$), Galí & Monacelli (2005) model obtains 0.93. Increasing the share of intermediate goods trade reduces the correlation. In particular, when trade occurs entirely at the intermediate level, the correlation is halved compared to the case where there is no intermediate trade. In this case, notice that there is no distinction between consumer price inflation and producer price inflation, as in McCallum & Nelson (2000), which makes both policy output the same. Obviously,

the assumption of trade in intermediate goods tends to dampen the nominal exchange pass-through and may contribute to the explanation of the so called low pass-through puzzle.

6 Conclusion

In this paper, we show that assuming trade in intermediate goods, or equivalently internationalized production in an otherwise standard New Keynesian small open economy model has important consequences. We document an additional channel through which external shocks and exchange rate fluctuations impact the economy, denoted as the “cost channel”. This channel exists because changes in relative prices or in the nominal exchange rate affect trade of intermediate goods and the marginal production cost of consumption goods producers through the price of imported inputs.

First, in contrast with Galí & Monacelli (2005), we show that exchange rate flexibility never insulates the small open economy from external shocks under internationalized production. Second, the overall macroeconomic volatility is reduced: trade in intermediate goods implies a smoother path of the economy and displays automatic stabilization properties. Third, the introduction of trade in intermediate goods may contribute to explain the low pass-through of nominal exchange rate fluctuations into consumption prices observed in the data.

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Appendix

The linearized model

Assuming $\widehat{\omega}_t = \widehat{w}_t - \widehat{p}_t$ and $\widehat{\omega}_t^* = \widehat{w}_t^* - \widehat{p}_t^*$, the linearized conditions are summarized as follows:

- Domestic block:

$$\begin{aligned}\psi \widehat{n}_t + \sigma \widehat{c}_t &= \widehat{\omega}_t - \alpha \widehat{s}_t \\ \sigma E_t \{ \widehat{c}_{t+1} \} - \sigma \widehat{c}_t &= \widehat{r}_t - E_t \{ \widehat{\pi}_{t+1} + \alpha \Delta \widehat{s}_{t+1} \} \\ \widehat{\pi}_t &= \beta E_t \{ \widehat{\pi}_{t+1} \} + \frac{(1 - \eta \beta)(1 - \eta)}{\eta} (\widehat{\omega}_t - \widehat{a}_t + \gamma \widehat{\rho}_t) \\ \widehat{y}_t &= \widehat{c}_t + \frac{\alpha(\sigma \mu + (1 - \alpha)(\sigma \mu - 1))}{\sigma} \widehat{s}_t \\ \widehat{a}_t + \widehat{n}_t &= (1 - \gamma) \widehat{y}_t + \gamma \widehat{c}_t^* + \phi \gamma (1 + (1 - \gamma)) \widehat{\rho}_t\end{aligned}$$

- International block:

$$\begin{aligned}\widehat{\rho}_t &= \widehat{s}_t + \widehat{\omega}_t^* - \widehat{\omega}_t + \widehat{a}_t \\ \widehat{c}_t &= \widehat{c}_t^* + \frac{1 - \alpha}{\sigma} \widehat{s}_t \\ \widehat{r}_t^* &= 0 \\ E_t \{ \widehat{\varepsilon}_{t+1} \} - \widehat{\varepsilon}_t - \widehat{r}_t &= 0\end{aligned}$$

- Exogenous shocks:

$$\begin{aligned}\widehat{a}_{t+1} &= \rho_a \widehat{a}_t + \xi_{a,t+1} \\ \widehat{c}_{t+1}^* &= \rho_{c^*} \widehat{c}_t^* + \xi_{c^*,t+1}\end{aligned}$$