Can sticky price small open economy models account for the important role of international disturbances?*

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Abstract

Existing sticky price small open economy models are unable to account for the observed influence of international business cycles on small open economies. We construct a two-sector new Keynesian model to address this puzzle. The set-up takes into account intermediate trade and producer heterogeneity, where goods and service industries differ in terms of price flexibility, trade intensity, technology, I-O structure, and the volatility of productivity innovations. The combination of intermediate markets and sectoral heterogeneity make international business cycles important for the small economy and model is able to account for the role of international disturbances typically found in empirical studies.

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1 Introduction

In a recent paper, Justiniano and Preston (2010, JP hereafter) argue that small open economy (SOE) dynamic sticky-price models are unable to account for the influence of foreign disturbances, evidenced by many empirical studies.[1] They set up a new Keynesian (NK) model along the lines of Galí and Monacelli (2005), extended with some bells and whistles that make it perform better empirically. The model is estimated using Canadian and US data, and in the baseline version foreign shocks account for less than 3 percent of the variability of key Canadian macroeconomic variables. Moreover, the model-implied cross-country correlations are close to zero for many macroeconomic variables.[2] The discrepancy between data and open-economy NK models is problematic because these models have become standard tools for forecasting and policy evaluations in many central banks and policy institutions.[3]

Justiniano and Preston (2010)'s results suggest that additional theoretical work on international transmission is needed to explain the co-movement of business cycles across countries. Our paper helps to fill this gap. We set up a standard open-economy NK model with two additional features, namely international markets for firm-to-firm trade in production inputs, and a two-sector

[1]The so-called VAR-FAVAR literature finds that foreign shocks explain a major part of the variance of domestic variables in SOE's, see, e.g., Kose, Otrok, and Whiteman (2003, 2008), Aastveit, Bjornland, and Thorsrud (2011), Crucini, Kose, and Otrok (2011), Mumtaz, Simonelli, and Surico (2011), and Kose, Otrok, and Prasad (2012).

[2]Other examples of SOE-NK models that seem to underplay the role of foreign disturbances (although not necessarily discussing this explicitly) are Adolfson, Laséen, Lindé, and Villani (2007, 2008), Rabanal and Tuesta (2010), Dib (2011), and Christiano, Trabandt, and Walentin (2011). In fact, the latter study reveals that it does not even help much to include a common, international TFP process.

[3]We focus on SOE-NK models, but Schmitt-Grohé (1998) document that also international real business cycle (BBC) models have problems accounting for foreign shocks in SOEs. In independent work Miyamoto and Nguyen (2014) extend the international RBC model to allow for more general utility functions and trade in intermediate inputs. They assume law-of-one-price, however, and it is an interesting question the extent to which their mechanism survives in an environment with low international pass-through of prices.

set-up as in the traditional open-economy macroeconomic models, where the two sectors differ in terms of trade intensity, labor intensity, input-output (I-O) structure, price flexibility and, finally, volatility of productivity innovations. The combination of intermediate goods trade and sector heterogeneity provides us with a simple framework which help to reconcile the open-economy NK models with data.[4]

International trade in production inputs introduce, as pointed out by Goldberg and Campa (2010), a new cost channel for the transmission of international shocks into the domestic economy. Consider, for example, a change in the exchange rate that makes imported goods cheaper. With trade in intermediate goods, this reduces the price on foreign inputs used in domestic production, and thus translates into lower marginal costs for domestic firms. In that sense, foreign innovations to technology (which lower import prices) have the potential to reproduce some important characteristics of domestic technology shocks. In fact, Goldberg and Campa argue that "[t]he dominant channel for CPI sensitivity is through the costs arising from imported input use in goods production. This channel is more important than changes in prices of imported goods directly consumed." Although highly realistic, international trade in inputs is largely ignored in the existing open-economy NK literature. A notable exception is Eyquem and Kamber (2013). They augment Galí and Monacelli (2005)

[4]We focus on a calibrated version of our model. Taken at face value, it is the discipline of the data that shuts down the international transmission of shocks in JP's model. For in a calibrated version of the model, a significant share of Canadian business cycle fluctuations are attributed to U.S. shocks (NBER Working Paper 14547). That calibration is unrealistic along one important dimension, however, namely that it implies that business cycle fluctuations in the U.S. is considerably larger than those in Canada. Moreover, the cross-country correlations are still out of line with the data in that calibration. We therefore consider both the importance of foreign shocks and cross-country correlations. For an estimated version of the current model with added bells and whistles as in JP, see Bergholt (2014). The latter work confirms the main results in the current paper and the mechanism we propose therefore survive being confronted with a broader set of data moments.

to include trade in intermediate inputs. In particular, they introduce an additional cost channel for domestic firms by assuming that producers of final goods combine inputs from both foreign and domestic intermediate producers. This is shown to improve the ability of the model in explaining international transmission of shocks, although the results are still far from the estimates reported in empirical studies.[5]

Our model features two sectors, namely one sector producing goods and one producing services.[6] Traditional open-economy models distinguish between traded and non-traded goods, where in most empirical applications the division is made between goods and services. We allow both goods and services to be traded, but trade intensity differs between the two sectors, as in the data. Sectoral heterogeneity is motivated by previous studies who find this to change propagations of economic disturbances along important dimensions. Horvath (2000) and Bouakez, Cardia, and Ruge-Murcia (2009) show that the presence of heterogeneous sectors in a closed economy, together with inter-firm trade in factor inputs, amplifies the propagation of disturbances and delivers additional persistence. Furthermore, the existence of these two features in an open economy allows shocks to enter domestic markets through some sectors, and propagate to others via cost channels. We show that taking these aspects into account is important for understanding transmission mechanisms in SOEs. In our framework a substantial share of international business cycles is driven by

[5]Other examples are Huang and Liu (2007) and , who set up a two-country model where intermediate inputs cross borders several times before becoming final goods. We focus on SOEs, which make multiple border-crossings irrelevant since small countries cannot create significant spillover effects back into the world economy.

[6]In an influential paper, Engel (1999) argues that fluctuations in the relative price of non-traded goods are irrelevant in explaining fluctuations in the real exchange rate. Similar results are reported by Chari, Kehoe, and McGrattan (2002). See, e.g., Bache, Sveen, and Torstensen (2013) for a recent discussion on the source of real exchange rate fluctuations. This evidence has motivated much research on macroeconomic models that focus exclusively on traded goods and sticky prices, see, e.g., Chari et al. (2002) and Galí and Monacelli (2005).

volatile manufacturing industries. Business cycle shocks enter home markets via trade with foreign manufacturing firms with relatively flexible price setting. The shocks are then transmitted to parts of the domestic economy with little international trade. Compared with the standard one-sector SOE-NK model, we get cross-country correlations and variance decompositions that closely resemble those found in the data.

The rest of the paper is organized as follows. We lay out the theoretical framework in Section 2. In Section 3 we present the results from our baseline calibration. We focus on simulated cross-country correlations and variance decompositions for the macroeconomic variables analyzed by Justiniano and Preston (2010). We inspect the economic mechanisms at work and provide intuitions for our main results. Section 4 concludes.

2 The model

In this section we develop a dynamic open-economy sticky price model with inter-firm trade and two heterogeneous sectors. To save space, we focus on the domestic economy below, but before turning to the details of the model, we outline its basic structure.

2.1 General structure

We consider a world consisting of two economies, home and foreign, and use superscript "F" as the notation for foreign economy variables. Later we will consider the limit where the home economy is small and has a negligible effect on the foreign economy, which is thought of as the rest of the world. The small open economy assumption allows us to model the foreign economy as a closed economy version of the domestic economy.

[Figure 1 about here.]

Figure 1 summarizes the relevant transmission channels in the model. In each country there are households, two sectors of firms, and a government. Households are infinitely lived and maximize expected lifetime utility. They supply labor in a perfectly competitive labor market and consume two types of products, namely goods and services, both of which are bundles of imports and domestically produced products. Firms in both sectors produce differentiated products using labor and materials and act under monopolistic competition. Products are either sold domestically or exported to the foreign economy. In both countries the products are used either for consumption purposes or as material input. Firms set prices in a staggered fashion à la Calvo (1983) and Yun (1996). We assume local currency pricing (LCP) along the lines of Betts and Devereux (2000).[7] We abstract from government spending and taxes, and monetary policy is specified in terms of a Taylor-type interest rate rule. Both domestic and foreign variables are measured in per capita terms.

2.2 Households

We assume that a representative household has access to a complete set of internationally traded contingent claims (for consumption). The household maximize expected lifetime utility and has the following period utility function

[7]An alternative price setting assumption often used in open-economy NK models is that of producer currency pricing (PCP). Examples include Galí and Monacelli (2005) and Eyquem and Kamber (2013). However, PCP implies unrealistically high pass-through from exchange rates to domestic prices, and arguably boosts the role of foreign shocks (see Gopinath, Itskhoki, and Rigobon (2010) for empirical evidence). Thus, we want to investigate how well our model can take international business cycles into account without help from PCP.

$$u\left(C_t, L_{k,t}\right) = \frac{{C_t}^{1-\sigma} - 1}{1-\sigma} - \chi_N \frac{{N_t}^{1+\varphi}}{1+\varphi}, \tag{1}$$

where C_t is period t consumption and N_t is hours worked that period. Parameter σ is the inverse of the intertemporal elasticity of substitution, and φ is the inverse of the Frisch labor supply elasticity. Moreover, χ_N is a scaling parameter, which will be used below to determine the fraction of time that is spent working (in a non-stochastic steady state).

Maximization is done subject to a sequence of budget constraints which take the following form:

$$P_t C_t + E_t\left\{\Lambda_{t,t+1} D_{t+1}\right\} \leq D_t + W_t N_t + T_t, \tag{2}$$

where P_t is the consumer price index (CPI) in period t, W_t is the nominal wage rate, and T_t are lump-sum transfers, including dividends resulting from ownership of firms. The stochastic discount factor for random nominal payments is denoted $\Lambda_{t,t+1}$ and D_{t+1} is the nominal payoff associated with the portfolio held at the end of period t.

The intertemporal optimality condition for consumption is

$$\Lambda_{t,t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+1}}, \tag{3}$$

where parameter β is the time discount factor and the gross nominal interest rate is given by $R_t = 1/E_t\left\{\Lambda_{t,t+1}\right\}$.

Labor supply is standard and given by

$$\frac{W_t}{P_t} = \chi_N C_t^{\sigma} N_t^{\varphi}. \tag{4}$$

2.3 Competitive aggregators

Along the lines of Bouakez et al. (2009), consumption and the materials composite specific to sector $k = (G, S)$ are aggregates of goods and services. The consumption aggregate is

$$C_t \equiv \Xi_C C_{G,t}^{\xi} C_{S,t}^{1-\xi},$$

where $\xi \in (0,1)$ is the share of goods in consumption and the constant $\Xi_C \equiv 1/\xi^{\xi}(1-\xi)^{1-\xi}$ is included to simplify some of the expressions that follow. Likewise, the material inputs are defined as

$$M_{k,t} \equiv \Xi_{Mk} M_{Gk,t}^{\zeta_k} K_{Sk,t}^{1-\zeta_k},$$

where $\zeta_k \in (0,1)$ is the share of manufactured goods in sector k materials, denoted $M_{Gk,t}$, and $\Xi_{Mk} \equiv 1/{\zeta_k}^{\zeta_k}(1-\zeta_k)^{1-\zeta_k}$. Moreover, we have $M_{k,t} \equiv \int_0^1 M_{k,t}(j)\, dj$, where $M_{k,t}(j)$ is the material input used by firm $j \in (0,1)$ in sector k.

Optimal allocation between goods and services in consumption implies

$$\frac{C_{G,t}}{C_{S,t}} = \frac{\xi}{1-\xi}\frac{P_{S,t}}{P_{G,t}} \tag{5}$$

and an equation for the CPI, $P_t \equiv P_{G,t}^{\xi} P_{S,t}^{1-\xi}$. We get analogous relationships for materials:

$$\frac{M_{Gk,t}}{M_{Sk,t}} = \frac{\zeta_k}{1-\zeta_k}\frac{P_{S,t}}{P_{G,t}} \tag{6}$$

and $P_{k,t}^{M} \equiv P_{G,t}^{\zeta_k} P_{S,t}^{1-\zeta_k}$ is the material price index in sector k.

We let bundles in each sector consist of domestic and foreign products. In particular, we construct the product $X_{k,t}$ in sector k according to

$$X_{k,t} \equiv \Xi_X X_{Hk,t}^{\bar{\alpha}_k} X_{Fk,t}^{1-\bar{\alpha}_k},$$

where $\Xi_X \equiv 1/\bar{\alpha}_k^{\bar{\alpha}_k}(1-\bar{\alpha}_k)^{1-\bar{\alpha}_k}$ and

$$\begin{aligned} X_{Hk,t} &\equiv \left[\int_0^1 X_{Hk,t}(j)^{\frac{\epsilon-1}{\epsilon}}\, dj\right]^{\frac{\epsilon}{\epsilon-1}}, \\ X_{Fk,t} &\equiv \left[\int_0^1 X_{Fk,t}(j)^{\frac{\epsilon-1}{\epsilon}}\, dj\right]^{\frac{\epsilon}{\epsilon-1}}. \end{aligned}$$

Here, $X_{Hk,t}$ is a CES index of the products $X_{Hk,t}(j)$, made by each domestic firm $j \in [0,1]$ in sector k. The home economy's aggregate import $X_{Fk,t}$ is an index of the different products $X_{Fk,t}(j)$ imported from firm j in sector k in the foreign economy. Parameter ϵ represents the elasticity of substitution between individual products produced within a given economy, while $\bar{\alpha}_k = 1-(1-\varsigma)(1-\alpha_k)$, which determines the weight of domestic products in $X_{k,t}$, is a function of the domestic share of world production, ς, and the degree of home bias in sector k, α_k.[8] The foreign block constitutes an equivalent system of equations.

Optimal allocation between domestic and imported goods implies:

$$\frac{X_{Hk,t}}{X_{Fk,t}} = \frac{\bar{\alpha}_k}{1-\bar{\alpha}_k}\frac{P_{Fk,t}}{P_{Hk,t}} \tag{7}$$

and $P_{k,t} \equiv P_{Hk,t}^{\bar{\alpha}_k} P_{Fk,t}^{1-\bar{\alpha}_k}$ is the corresponding price index for sector k goods. Last, optimal allocation of goods within each sector implies

$$X_{Hk,t}(j) = \left(\frac{P_{Hk,t}(j)}{P_{Hk,t}}\right)^{-\epsilon} X_{Hk,t}, \tag{8}$$

$$X_{Fk,t}(j) = \left(\frac{P_{Fk,t}(j)}{P_{Fk,t}}\right)^{-\epsilon} X_{Fk,t}. \tag{9}$$

where $P_{Hk,t} \equiv \left[\int_0^1 P_{Hk,t}(j)^{1-\epsilon}\, dj\right]^{\frac{1}{1-\epsilon}}$ and $P_{Fk,t} \equiv \left[\int_0^1 P_{Fk,t}(j)^{1-\epsilon}\, dj\right]^{\frac{1}{1-\epsilon}}$ are sector k domestic and imported prices, respectively. The foreign economy allocates resources according to a similar set of optimality conditions.

2.4 Firms

There is a continuum of firms indexed on the unit interval in each sector $k = (G, S)$. Each firm j in sector k has access to a Cobb-Douglas production func-

[8] For the foreign economy, the corresponding parameter is defined as $\bar{\alpha}_k^F = 1-\varsigma(1-\alpha_k)$. This setup encompasses many interesting special cases, including i) complete autarky ($\alpha_k = 1$), ii) perfectly integrated markets ($\alpha_k = 0$), and iii) the limiting case of a small open economy ($\varsigma \to 0$).

tion:

$$Y_{k,t}(j) = Z_{k,t} M_{k,t}(j)^{\phi_k} N_{k,t}(j)^{1-\phi_k}, \tag{10}$$

where $M_{k,t}(j)$ and $N_{k,t}(j)$ are firm j in sector k's use of materials and labor respectively, and $\phi_k \in (0,1)$ is the share of materials in production in that sector. In the limit as ϕ_k approaches zero, we get back to the standard two-sector open-economy model. The sector-specific technology level follows an AR(1) process in log-linear form:

$$\frac{Z_{k,t}}{Z_k} = \exp(\varepsilon_{k,t}) \left(\frac{Z_{k,t-1}}{Z_k} \right)^{\rho_z} \tag{11}$$

$\varepsilon_{k,t}$ is a series of i.i.d. innovations to total factor productivity and $\rho_z \in (0,1)$.

Let θ_k denote the probability that a given firm in sector k is able to reset a price. Let $\{\bar{P}_{Hk}(j), \bar{P}^F_{Hk}(j)\}$ denote the pair of optimal prices ($\bar{P}^F_{Hk}(j)$ is evaluated in the foreign currency) for a firm j in sector k that is able to reoptimize in period t. Finally, $X_{Hk}(j)$ and $\tilde{X}^F_{Hk}(j)$ denote the (per capita) domestic and foreign demand for output from that firm. The price setter chooses a sequence of $\left\{ Y_k(j), X_{Hk}(j), \tilde{X}^F_{Hk}(j), P_{Hk}(j), P^F_{Hk}(j), M_k(j), N_k(j) \right\}$ to solve a profit maximization problem of the following form:

$$\begin{aligned} \max \sum_{s=0}^{\infty} E_t \Big\{ \Lambda_{t,t+s} \Big[& P_{Hk,t+s}(j) X_{Hk,t+s}(j) + \mathcal{E}_{t+s} P^F_{Hk,t+s}(j) \tilde{X}^F_{Hk,t+s}(j) \Big] \\ & - \left[P^m_{k,t+s} M_{k,t+s}(j) + W_{k,t+s} N_{k,t+s}(j) \right] \Big\} \end{aligned}$$

subject to

$$\begin{aligned}
X_{Hk,t+s}(j) + \tilde{X}^F_{Hk,t+s}(j) &= Y_{k,t+s}(j) \\
Y_{k,t+s}(j) &= Z_{k,t+s} M_{k,t+s}(j)^{\phi_k} N_{k,t+s}(j)^{1-\phi_k} \\
X_{Hk,t+s}(j) &= \left(\frac{P_{Hk,t+s}(j)}{P_{Hk,t+s}}\right)^{-\epsilon} X_{Hk,t+s} \\
\tilde{X}^F_{Hk,t+s}(j) &= \left(\frac{P^F_{Hk,t+s}(j)}{P^F_{Hk,t+s}}\right)^{-\epsilon} \tilde{X}^F_{Hk,t+s} \\
P_{Hk,t+s+1}(j) &= \begin{cases} \bar{P}_{Hk,t+s+1}(j) & \text{with probability } 1-\theta_k \\ P_{Hk,t+s}(j) & \text{with probability } \theta_k \end{cases} \\
P^F_{Hk,t+s+1}(j) &= \begin{cases} \bar{P}^F_{Hk,t+s+1}(j) & \text{with probability } 1-\theta_k \\ P^F_{Hk,t+s}(j) & \text{with probability } \theta_k \end{cases}
\end{aligned}$$

where $\tilde{X}^F_{Hk,t}$ is period t foreign demand for domestically produced sector k goods, measured in domestic per capita units. Moreover, $\mathcal{E}_t$ is the nominal exchange rate, measured as the price of foreign currency in terms of domestic currency.

The first-order conditions for price setting are given by:

$$0 = E_t \sum_{s=0}^{\infty} (\theta_k)^s \Lambda_{t,t+s} X_{Hk,t+s}(j) \left[\bar{P}_{Hk,t}(j) - \mu MC_{k,t+s}(j)\right] \tag{12}$$

$$0 = E_t \sum_{s=0}^{\infty} (\theta_k)^s \Lambda_{t,t+s} \tilde{X}^F_{Hk,t+s}(j) \mathcal{E}_{t+s} \left[\bar{P}^F_{Hk,t}(j) - \mu \frac{MC_{k,t+s}(j)}{\mathcal{E}_{t+s}}\right] \tag{13}$$

where $MC_{k,t}(j)$ denotes a sector k firm j's period t nominal marginal costs and $\mu \equiv \frac{\epsilon}{\epsilon-1}$ is the frictionless mark-up. The former reads

$$MC_{k,t}(j) = \frac{W_{k,t}}{(1-\phi_k)\frac{Y_{k,t}(j)}{N_{k,t}(j)}}. \tag{14}$$

Equations (12) and (13) reflect the fact that prices are set in a forward-looking manner. When setting a price, the firm takes rationally into account both current and future expected marginal costs in those states of the world where their chosen prices are still posted. Finally, we obtain a standard condition for cost-minimization:

$$\frac{M_{k,t}(j)}{N_{k,t}(j)} = \frac{\phi_k}{1-\phi_k}\frac{W_{k,t}}{P^M_{k,t}} \tag{15}$$

Together with (14), equation (15) implies that $MC_{k,t}(j) = MC_{k,t}$ for all j in sector k. Firms in the foreign economy solve a similar profit maximization problem, and arrive at a system of equations equivalent to the one just described.

2.5 Market clearing, risk sharing and monetary policy

Clearing of the labor markets requires that hours worked is given by

$$N_t = N_{G,t} + N_{S,t}, \tag{16}$$

where $N_{k,t} = \int_0^1 N_{k,t}(j)\, dj$. For both sectors in the economy, the final product $X_{k,t}$ can be used either in consumption or in production. Sector level market clearing implies that

$$X_{k,t} = C_{k,t} + \sum_{l=1}^{K} M_{kl,t}, \tag{17}$$

where $M_{kl,t}$ is sector l's use of sector k's goods as materials.

Trade between the world economy and the SOE becomes negligible from the world economy's point of view when $\varsigma \to 0$. To see this, we use the previously defined variable $\tilde{X}^F_{Hk,t}(j)$, which denotes a domestic sector k firm j's export expressed in domestic per capita units. Similarly, we let $X^F_{Hk,t}(j)$ denote that firm's export in foreign per capita units. This notation implies that $\tilde{X}^F_{Hk,t}(j) = \frac{1-\varsigma}{\varsigma} X^F_{Hk,t}(j)$. When this equation is combined with the relevant optimality condition for foreign import, and the home block's trade equations are evaluated in the limit as $\varsigma \to 0$, we get the following system of trade optimality conditions for the small open economy:

$$\frac{X_{Hk,t}}{X_{Fk,t}} = \frac{\alpha_k}{1-\alpha_k} \frac{P_{Fk,t}}{P_{Hk,t}}, \tag{18}$$

$$\frac{\tilde{X}^F_{Hk,t}}{X^F_{k,t}} = (1-\alpha_k) \frac{P^F_{k,t}}{P^F_{Hk,t}}. \tag{19}$$

We let $X^F_{k,t}$ denote total demand in the foreign sector k. It is clear from the optimality conditions with respect to $X^F_{Fk,t}$ and $X^F_{Hk,t}$ in the foreign block, as well as the export demand schedule $\tilde{X}^H_{Fk,t}$, that $\varsigma \to 0$ implies

$$X^F_{Fk,t} = X^F_{k,t}, \tag{20}$$

and $X^F_{Hk,t} = \tilde{X}^H_{Fk,t} = 0$.

In both sectors demand equals supply for each product j. Aggregating over all products in each sector gives

$$Y_{k,t} = \int_0^1 Y_{k,t}(j)dj = X_{Hk,t}\Delta_{Hk,t} + \tilde{X}^F_{Hk,t}\Delta^F_{Hk,t}, \tag{21}$$

where the terms $\Delta_{Hk,t} = \int_0^1 \left(\frac{P_{Hk,t}(j)}{P_{Hk,t}}\right)^{-\epsilon} dj$ and $\Delta^F_{Hk,t} = \int_0^1 \left(\frac{P^F_{Hk,t}(j)}{P^F_{Hk,t}}\right)^{-\epsilon} dj$ denote relative price dispersions. These are equal to one up to the first order.

We define terms of trade in sector k between domestic and foreign producers as $\mathcal{T}_{k,t} \equiv \frac{\mathcal{E}_t P^F_{Hk,t}}{P_{Fk,t}}$, i.e., the ratio of export prices to import prices. Both are in domestic currency. Moreover, we denote the bilateral real exchange rate between the home country and the foreign economy in terms of consumption goods as $\mathcal{S}_t \equiv \frac{\mathcal{E}_t P^F_t}{P_t}$ (P^F_t is the CPI in the foreign country, measured in local currency). Combining the Euler equation in the world economy with the one in the home country and assuming symmetric initial conditions, a standard risk-sharing condition emerges:

$$C_t = \mathcal{A} C^F_t \mathcal{S}_t^{\frac{1}{\sigma}}, \tag{22}$$

where $\mathcal{A} = \frac{C_0}{C^F_0}\left(\frac{1}{\mathcal{S}_0}\right)^{\frac{1}{\sigma}}$ is normalized to one without loss of generality.

For completeness, let us define gross domestic product in sector k in units of consumption goods, denoted $GDP_{k,t}$, as

$$GDP_{k,t} \equiv \frac{P_{Hk,t}}{P_t} X_{Hk,t} + \frac{\mathcal{E}_t P^F_{Hk,t}}{P_t} \tilde{X}^F_{Hk,t} - \frac{P^M_{k,t}}{P_t} M_{k,t}$$

$$= \frac{P_{k,t}}{P_t} C_{k,t} + TB_{k,t} + \frac{P_{k,t}}{P_t} \sum_{l=1}^{K} M_{kl,t} - \frac{P_{k,t}^M}{P_t} M_{k,t}, \tag{23}$$

where the trade balance is given by

$$TB_{k,t} \equiv \frac{\mathcal{E}_t P_{Hk,t}^F}{P_t} \tilde{X}_{Hk,t}^F - \frac{P_{Fk,t}}{P_t} X_{Fk,t}. \tag{24}$$

The economy-wide GDP is defined as

$$GDP_t \equiv \sum_{k=1}^{K} GDP_{k,t} = C_t + TB_t, \tag{25}$$

where we have used that $\sum_{k=1}^{K} P_{k,t} \sum_{l=1}^{K} M_{kl,t} = \sum_{k=1}^{K} P_{k,t}^M M_{k,t}$. The aggregate trade balance is here defined as $TB_t \equiv \sum_{k=1}^{K} TB_{k,t}$.

Finally, we specify monetary policy. The central bank is assumed to follow a simple Taylor rule of the form

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r} \left[\left(\frac{\Pi_t}{\Pi}\right)^{\rho_\pi} \left(\frac{GDP_t}{GDP}\right)^{\rho_y}\right]^{1-\rho_r}, \tag{26}$$

where parameter ρ_r captures interest rate smoothing, and ρ_π and ρ_y the responsiveness to inflation and output.

Sector heterogeneity induces a non-symmetric equilibrium across different industries. Model equations are log-linearized around a non-stochastic steady state. The resulting linear system is then solved numerically for the rational expectations solution. Steady state equations and the linearized system of the home economy are provided in an on-line appendix.

3 Quantitative analysis

Our aim is to analyze the importance of foreign disturbances for the small open economy. To this end, we use the theoretical framework developed above to explain the role of internationalized production and sectoral heterogeneity. Before turning to the results, we briefly discuss the calibration of our baseline model.

3.1 Calibration

We calibrate the small open economy to Canadian data, and assume that US approximates the large closed economy. This country pair has been used in a number of two-country SOE studies, including Schmitt-Grohé (1998) and Justiniano and Preston (2010). To facilitate a comparison with JP, we set comparable parameters (β, σ, φ, ϵ, ρ_r, ρ_π, ρ_y and ρ_z) to the (estimated and calibrated) values in their paper. Sector-specific parameters, on the other hand, are comparable to those used in Bouakez et al. (2009). Our cross-sectoral dimension is much simpler, however, given that we focus only on two sectors, goods and services, and we aggregate "durable goods", "non-durable goods", "construction", "mining" and "agriculture" into one common "goods" category. Parameter values are reported in Table 1.

The period length is one quarter. The time discount factor is therefore consistent with a yearly return of about 4 percent. We choose $\epsilon = 8$, which implies a profit margin of about 14%. Finally we solve for the value of χ_N that implies steady state hours equal to one third.

[Table 1 about here.]

The remaining parameters are related to sector heterogeneity and deserve further attention. The probabilities of re-optimizing prices in the two sectors are set roughly equal to the weighted averages of corresponding estimates in the six-sector model by Bouakez et al. (2009). It is worth emphasizing that the values we use for θ_G and θ_S imply that goods producers change price about 3 times every year, while service producers keep the same price for more than 6.5 quarters on average. This is the first important type of sector heterogeneity in the model, and is also consistent with a number of micro studies, see, e.g., Nakamura and Steinsson (2008). Turning to productivity, we let technology innovations in the goods sector be 5 times more volatile compared to shocks in the service sector. This is based on Bouakez et al. (2009), who find that technology shocks in the service sector are of negligible size compared with most other industries (often less than 1%). The difference in technology shocks across sectors is the second important source of heterogeneity. We also rescale the absolute size of aggregate TFP volatility across specifications to obtain a standard deviation in GDP in both countries equal to 3.5%, consistent with linearly de-trended data for the US and Canada (see, e.g., Dib (2011)).

Finally, we calibrate a number of parameters to target trade flows reported in OECD data.[9] We calibrate our goods sector by aggregating the I-O data from industries SIC01-SIC45, while the service sector constitutes industries SIC50-SIC72.[10] These industries are exhaustive in the sense that they aggregate to privately produced GDP in both economies. The data reveal large differences across the two sectors. For instance, the export-to-GDP ratio is 16% in the service sector and about 100% in the goods sector.[11] This feature constitutes the

[9]The data are taken from the Structural Analysis Input Output (Total) Database constructed by OECD, see http://www.oecd.org/trade/input-outputtables.htm for more information.

[10]The statistical agencies in Canada and the US generally use the North American Industry Classification System (NAICS) rather than the international SIC standard. However, it is a simple matter to move between systems at this level of aggregation. The NAICS codes for our sectors are 11-33, and 41-54 respectively.

[11]The aggregate export share is about 40%, as the service sector is responsible for most of aggregate GDP.

third key source of sector heterogeneity in the model. Turning to data on materials, we see that they are responsible for a considerably higher cost share in the goods sector than in the service sector. The I-O matrices also demonstrate the substantial trade in intermediate goods across sectors. For instance, the service sector in Canada buys about 35% of its materials from the goods sector (which trades extensively in foreign markets). This is how trade across sectors provides indirect import in the model, and thereby serves as a potential amplification mechanism for foreign shocks. The I-O matrices represent the fourth important source of sector heterogeneity in the model.

3.2 Sectoral heterogeneity and the importance of foreign shocks

We now turn to the central question of the current paper: Are foreign disturbances important for business cycles in our small open economy? To facilitate comparison with JP, we focus on the same five variables as they employ in their study, namely GDP, hours worked, the nominal interest rate, CPI inflation, and the real wage.

To isolate the role of sector heterogeneity for the transmission of foreign shocks, we consider a benchmark model featuring symmetric sectors. We allow for trade in intermediate inputs, but we set all sector level parameters as economy-wide averages of the ones in the baseline with sectoral heterogeneity. More precisely, we let the share of materials in production be 0.49, and we let the consumption and material inputs in all sectors consist of equal shares from the two sectors. Innovations in each of the sectors are driven by productivity shocks with common volatility. The benchmark model is similar to the one analyzed by Eyquem and Kamber (2013) in the sense that trade takes place between symmetric firms with identical I-O structures.[12]

[Table 2 about here.]

The results for the benchmark are reported in Table 2. Consider first the correlations between domestic and foreign variables. They are positive, but considerably lower than in the data. JP, for instance, report cross-country correlations between these variables – between 0.7 and 0.85 for all variables except for the rate of inflation and hours worked. For the latter variables, the correlation coefficients are about 0.5 and 0.25 respectively. Thus, the symmetric version of our model is not able to match the co-movement of business cycles across countries. Nevertheless, the correlation coefficients in Table 2 are still comparable with those reported by Eyquem and Kamber (2013),[13] and they are significantly better than those obtained by JP, who report point estimates of less than 0.1 for all variables.

Second, we consider the variance decomposition. Foreign shocks explain between 8% and 22% of the variation in domestic variables, which again is considerably less than that reported in the empirical analysis by JP.[14] They report a share of foreign factors in explaining most domestic variables of about 70%, thus pointing to an important role played by foreign disturbances. The benchmark model still stands in sharp contrast to the NK model in JP, which suggests that less than 3% of the fluctuations in the relevant variables are explained by

[12] However, the LCP assumption in our model implies deviations from the law of one price in the short run, and substantially less pass-through from exchange rates to the CPI. This arguably reduces the role of foreign shocks.

[13] Eyquem and Kamber (2013) report a negative correlation between domestic and foreign output for their calibrated version of Galí and Monacelli (2005). When the authors add trade in intermediate inputs, the cross-country correlation in GDP increases to 0.14 or 0.29, depending on the exact model specification. Note that the correlation between foreign and domestic consumption is high in all these models. This is due to the risk-sharing assumption.

[14] The symmetry of the model implies that shocks to the goods and the service sector (within countries) have the same impact on aggregate variables.

foreign factors. For example, the share of foreign shocks in the domestic variance of output is about 1% in that model. We assign this improvement to internationalized production, as in Eyquem and Kamber (2013). The intuition is as follows. In a model à la Galí and Monacelli (2005), foreign productivity shocks will have two counteracting effects on the domestic economy. To the extent that domestic inflation rate falls, the central bank will engineer a reduction in the real interest rate, which will have an expansionary effect on domestic demand. On the other hand, there is expenditure switching from expensive domestically produced products to cheaper foreign products. With firm-to-firm trade, there will also be a reduction in costs for domestic firms. Therefore foreign shocks are more important for the domestic economy.

Next, we turn to our baseline model and ask whether foreign shocks are important for business cycles. The answer is given in Table 3. The baseline model delivers cross-country correlations in the variables of interest that are close to those in the data. The correlation between foreign and domestic value added is 0.71, compared with 0.25 in the benchmark model, and there are comparable increases for the nominal interest rate, the rate of inflation, and the real wage. These numbers are closely in line with those found in empirical studies, see e.g. Imbs (2004) and Heathcote and Perri (2004).[15]

[Table 3 about here.]

As far as the importance of foreign shocks is concerned, they now account for more than 49% of the variance in most domestic variables, including GDP. The importance of international business cycles evident in our results is consistent with a number of empirical studies. For instance, Crucini et al. (2011)

[15]The correlation between domestic and foreign hours has gone from 0.29 to 0.66, and is now actually too high. We attribute this to the assumption of a perfectly competitive labor market.

estimate a FAVAR model using data from seven developed economies and find that foreign shocks explain between 36% and 74% of the variation in Canadian GDP (see Table 1 and Table 7 in their paper).[16] The authors also find that foreign productivity shocks are the most important international disturbance for Canada. Their median variance share in Canadian output is 54%. Another influential study is Kose et al. (2003). They estimate a Bayesian factor model, which attributes about 36% of the variation in Canadian output to a global business cycle and another 36% to regional cycles. The SUR model estimated by JP provides further evidence, with between 44% and 98% of the variation in Canadian GDP attributed to foreign shocks. Similar findings are reported for Canadian hours, the interest rate, inflation, wages, and the exchange rate (see their Table 1). Interestingly, the variance decompositions for all variables in our baseline model are within the Bayesian probability bands reported by JP.

Why is heterogeneity important for understanding how foreign shocks are transmitted into a small open economy? Above we have argued that internationalized production introduces a cost channel for the transmission of international shocks. Increased productivity in a foreign sector reduces the prices of products in that sector. To the extent that those products are used domestically as materials in production, the cost of production falls. Productivity shocks in a foreign sector will therefore tend to imply a larger increase in domestic production the more important that sector is for domestic production and the more flexible prices are in that sector. The latter is important in order to generate a drop in domestic prices. Compared with a symmetric model, heterogeneity increases the importance of foreign shocks since firms that trade extensively in international markets are important suppliers of production inputs, have more

[16] On average in the seven economies, 47% of the output variation is driven by common business cycles. Thus, Canada does not seem to be a special case.

flexible prices, and face relatively volatile productivity.

3.3 Inspecting the mechanism

We analyse the importance of sectoral heterogeneity in two steps. First, we consider the dynamic consequences of the two foreign shocks by inspecting impulse responses. Second, we analyse the respective role of volatility of productivity innovations, trade intensity, technology and I-O structure, and price setting for the role of foreign shocks in domestic business cycles.

3.3.1 Impulse responses from sector-specific productivity shocks

We begin by analysing the dynamic consequences of a productivity shock in the foreign goods market. The results are shown in Figure 2. The effects on aggregate variables in the foreign economy are similar to the ones we know from a one sector model. Foreign value added and real wages increase, while prices and the use of labor fall.[17] The latter is due to the fact that prices are sticky. Firms are demand-constrained and if prices do not fall sufficiently, they will use less labor to produce.

[Figure 2 about here.]

What about the small open economy? As far as aggregate variables are concerned, the dynamic consequences of the foreign technology shock on aggregate variables are similar to those of the foreign economy. The decrease in the price of foreign goods implies a significant decline in goods prices in the domestic economy. The reason is both the high trade intensity for those products and the

[17] Compared with a one-sector set-up, there is, however, amplification and increased persistence, as argued by Bouakez et al. (2009).

resulting lower production costs for domestic producers of both goods and services. The decline in domestic CPI implies a reduction in domestic real interest rates and therefore an increase in consumption. Due to sticky prices, the fall in the price of materials implies not only higher domestic production, but also lower demand for hours.

Next, we consider the two sectors. There are four different effects on domestic firms within each sector. Lower real interest rates drive up domestic households' demand for all products, but at the same time household members substitute foreign for domestic products when the former become less expensive. This is similar to a one-sector model without internationalized production. In our model, there are two additional effects. First, the foreign technology shock makes imported intermediate goods cheaper and therefore domestic firms can produce at a lower cost. This cost effect is important for both sectors. Second, there will be expenditure switching in the material goods market, as foreign goods used as materials become relatively cheaper compared with domestically produced goods. Expenditure switching, both for consumer goods and materials, is contractionary for domestic firms. The net effect on economic activity at the sector level depends on the relative importance of the different effects. In the baseline calibration, increased import and reduced export lead to a negative trade balance, but GDP in both sectors actually increases. This is interesting and important since sectoral GDP series show considerable co-movement in the data, a fact that is hard to reproduce in general equilibrium models.[18] Below we argue that shocks to productivity in the foreign goods sector is important for understanding international co-movement. The figure shows that we are able to get high international co-movement without sacrificing sectoral co-movement.

[18] See e.g. Raddatz (2010), Veldkamp and Wolfers (2007), Hornstein (2000) and Hornstein and Praschnik (1997).

In addition to the increase in GDP, hours drop substantially in this sector. The reason is substitution away from labor towards cheaper materials. Finally, despite the drop in labor demand, there is an increase in real wages due to the surge in household consumption.

The dynamic consequences are similar for the domestic service sector. The marginal costs fall and firms lower their prices. The reduction in real interest rates increases consumption demand, which to a large extent falls on domestic producers. The result is that GDP in the service sector rises even more than in the goods sector. The general lesson from Figure 2 is that productivity changes in foreign industries are transmitted into the domestic economy through some sectors with relatively flexible prices and intensive foreign trade, and then propagated into other sectors with more sticky prices via firm-to-firm trade.

[Figure 3 about here.]

Next, we consider the dynamic consequences of a positive technology shock in the foreign service sector. The results are shown in Figure 3. There is a modest change in domestic CPI inflation, the interest and hours worked, and, moreover, aggregate GDP and real wages move slightly in the opposite direction of their foreign counterparts on impact. Two points are worth making. First, the low import share in the service sector limits the direct transmission from foreign to domestic products. Second, the high degree of price stickiness limits the response of service sector inflation to changes in marginal costs.

As far as the two sectors are concerned, we see that both hours, inflation, GDP and the trade balance in the domestic goods sector respond more than in the service sector. The reason is the real exchange rate appreciation which comes about due to the difference in real interest rates. This implies expenditure switching, both for consumption and materials, between foreign and domestic goods and services. And since there is higher pass-through for goods than for services, this effect is more prevalent for goods. All in all, however, productivity increases in the foreign service sector have a modest impact on domestic markets.

3.3.2 The importance of sectoral heterogeneity

Next, we analyse the respective role of heterogeneity in the volatility of productivity innovations, trade intensity, price rigidity, technology, and I-O structure for the role of foreign shocks in domestic business cycles.

We start by assuming that innovations in each of the sectors are driven by productivity shocks with common volatility, as in the benchmark model. The results are given in Panel A in Table 4. Removing sectoral heterogeneity in productivity innovations significantly affects the model's ability to account for the cross-country correlations in the data. The correlation between foreign and domestic output decreases from 0.71 in the baseline calibration to 0.44 with symmetric shocks. There are similar deteriorations for the other macroeconomic variables. In the model with symmetry, foreign shocks account for about one fourth of the variation in domestic GDP, while in the baseline model that fraction is above 50 percent. The reason is simple. Shocks to productivity in the foreign goods sector imply considerable international transmission, while shocks to the service sector do not. In a model where the innovations in the two sectors are similar, there will thus be less international transmission of shocks than if the volatility of productivity in the goods sector is relatively higher.

[Table 4 about here.]

An important difference between goods and services is their trade intensity. Next we therefore consider the effect of assuming a similar trade intensity in the two sectors. The results are reported in Table 4 in Panel B. Asymmetric trade intensity is important for the result in our baseline model. Assuming symmetry reduces the cross-country correlation and it is between 40 and 50 percent for most macroeconomic variables. Furthermore, there is a considerable reduction in the importance of foreign shocks, from 52 to about 15 percent for GDP, and there are similar reductions for the other variables. The intuition is as follows: in the symmetric case there is more trade in services and less trade in goods. Therefore more of the products that are traded have relatively little volatility in productivity and high price rigidity, both of which will reduce international transmission of shocks.

Next, we consider the effect of symmetric price stickiness across the two sectors. Panel C in Table 4 reports the results. Assuming symmetry in price duration across goods and services reduces both cross-country correlations and the importance of foreign shocks. The cross-country correlation between domestic and foreign GDP falls from 71 to 54, and foreign shocks account for 36 compared with 52 percent in the baseline model. This is interesting and important since there is considerable heterogeneity in price rigidity between the two sectors in the baseline model. The reason is that there are counteracting effects. Increasing price stickiness in the goods sector reduces the domestic price impact of an increase in productivity in the foreign goods sector, and the impact on domestic GDP is lower. However, higher price stickiness in the goods sector reduces the impact on foreign GDP too. Moreover, the reduced price duration in the service industry, makes that sector react more to a given reduction in the price of imported goods.

Last, we let the two sectors have homogeneous technology and I-O structure. As in the benchmark model, we let the share of materials in production be 0.49 as in the economy average and material inputs in both sectors consist of equal shares from the two sectors. The results are given in Panel D and E in Table 4. Homogeneous technology increases cross-country correlations and the importance of foreign shocks somewhat. The reason is that shocks in the foreign goods sector will be more important for domestic service producers, since domestic service firms now use more goods in production. In Figure 2 we see that GDP in the service industry increases more than in the goods sector following foreign productivity shocks. If productivity in the foreign goods sector becomes more important in the service sector and less important in the goods sector, overall GDP will increase more.

Homogeneous I-O structure, on the other hand, decreases both cross-country correlations and the importance of foreign shocks. More precisely, the cross-country correlation in GDP decreases from 71 to 60, and the importance of foreign shocks for GDP falls from 52 to 37 percent. The reason is that foreign goods prices now have less impact on prices for domestic goods. The limited drop in domestic goods sector inflation creates a muted response in the domestic real interest rate, and there is a smaller increase in domestic demand. Domestic service GDP reacts less and there is a larger discrepancy between domestic and foreign GDP. We refer to the on-line appendix for a comprehensive robustness analysis of the results.

4 Concluding remarks

In the current paper we revisit the question of whether a sticky price open-economy model can account for the observed international co-movement between macroeconomic variables at the business cycle frequency in small open economies. To this end, we extend the model to include inter-firm trade and sectoral heterogeneity between producers of goods and services. Our main result is that these features are sufficient to reconcile the model with data along important international dimensions. Simulated cross-country correlations and variance decompositions are equal to about 0.7 and 50%, respectively, which is consistent with empirical studies.

Not only does our model attribute an important role to foreign disturbances, it also provides us with a theory which helps in understanding how international business cycles are likely to affect domestic markets. In particular, the combination of intermediate trade and sector heterogeneity in our model induces strong sectoral spillovers, where disaggregate shocks propagate across both industries and countries via intermediate markets. First, foreign shocks enter parts of the domestic economy where there is substantial international trade – the goods sector in our model. Second, this naturally leads to fluctuations in prices for these traded goods. The fluctuations can be large, especially because goods prices are relatively flexible. Third, as less traded sectors such as services use goods extensively as input, the shock propagates into the large, but relatively non-traded, service sector.

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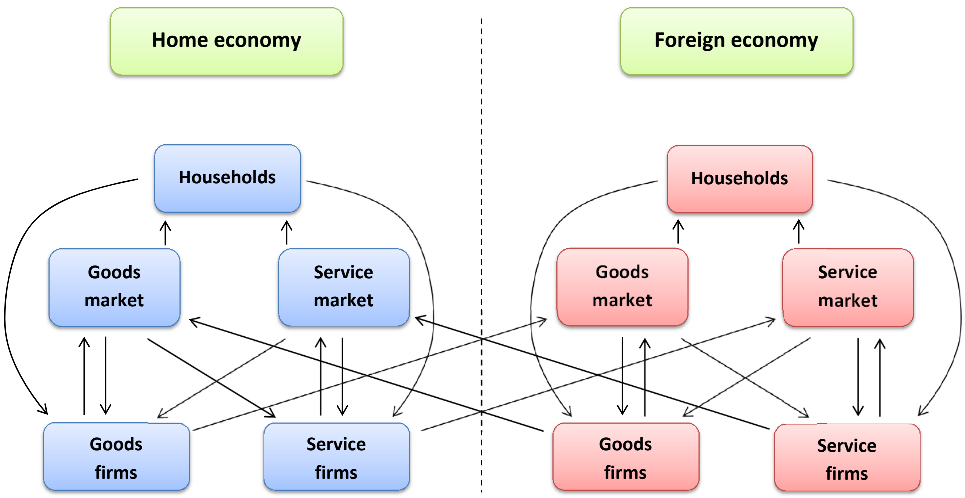
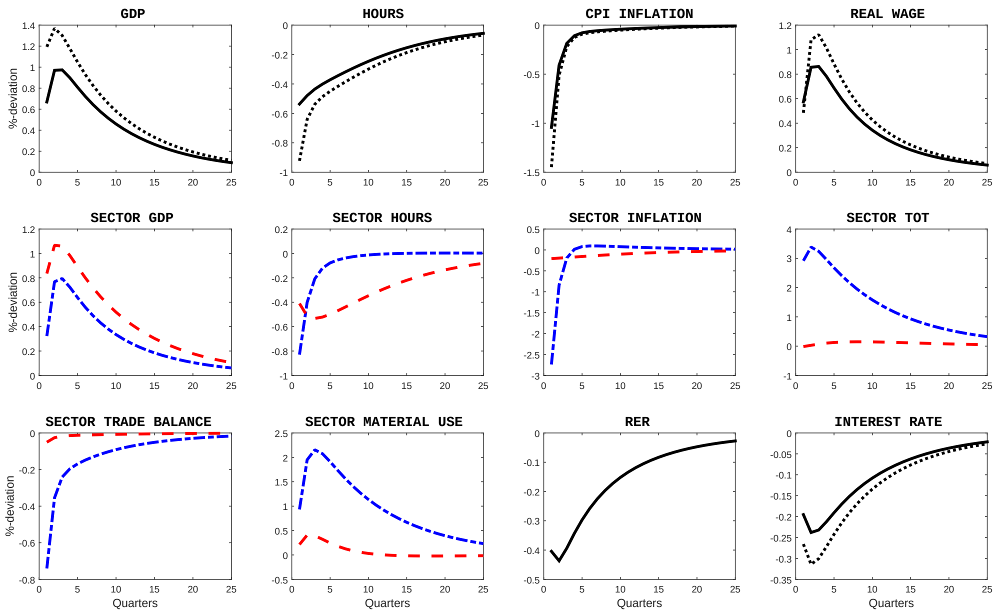
Figure 1: A bird's-eye view of the model economies



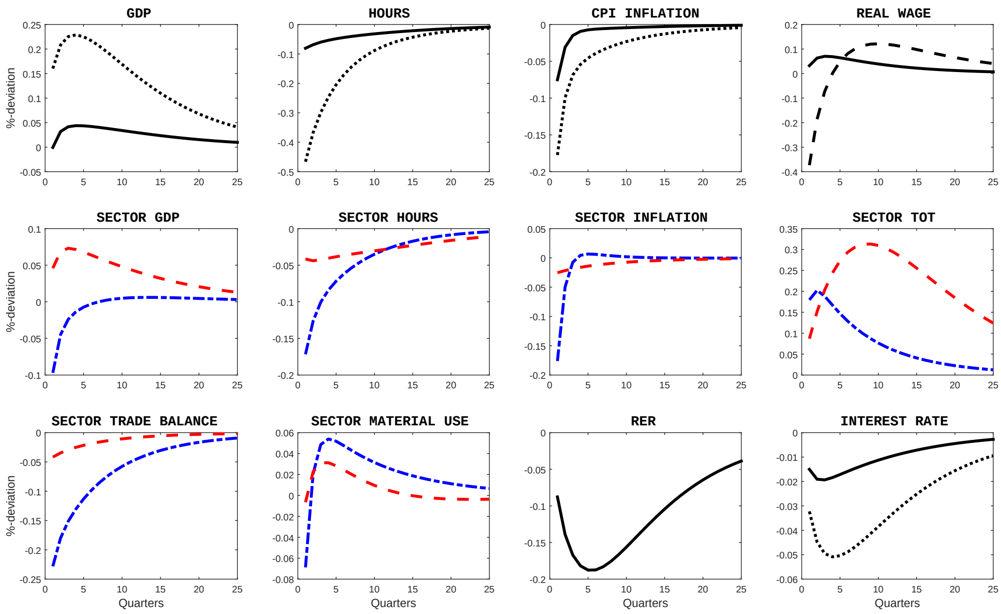
Note: The stippled vertical line represents the country border between our two model economies. Arrows summarize the trade (quantity) flows. Arrows across the border summarize the international trade activity.

Figure 2: A productivity shock in the foreign goods sector



Note: The black solid line corresponds to the small open economy, while black dotted line to the large economy. The blue dash-dotted line shows the goods sector and the red dashed line the service sector. RER denotes the CPI real exchange rate and trade balances are measured as fractions of steady state GDP in each sector.

Figure 3: A productivity shock in the foreign service sector



Note: See Figure 2.

Table 1: Calibration of parameters

Parameter	*Description*	*Value*	
Common:			
β	Time discount factor	0.99	
σ	Intertemporal elasticity of substitution	1.4	
φ	Inverse elasticity of labor supply	1.3	
χ_N	Set to fit steady state hours equal to $1/3$	23.7	
ϵ	El. of substitution, individual goods	8	
ρ_r	Taylor rule – inflation smoothing	0.9	
ρ_π	Taylor rule – CPI inflation	2	
ρ_y	Taylor rule – output	0.2	
ρ_z	AR(1) coefficient technology	0.9	
Sector specific:		*Goods*	*Services*
ϕ_k	Materials share in gross output Home	0.60	0.34
ϕ_k^F	Materials share in gross output Foreign	0.59	0.32
θ_k	Nominal price stickiness	0.25	0.85
σ_k	Standard deviation – technology Home	0.045	0.009
σ_k^F	Standard deviation – technology Foreign	0.030	0.006
Calibrated targets:			
α_k	Export share of GDP	1.00	0.16
ξ	Share of sector consumption Home	0.33	0.67
ξ^F	Share of sector consumption Foreign	0.30	0.70
ζ_k	Input-output matrix Home	0.80	0.35
		0.20	0.65
ζ_k^F	Input-output matrix Foreign	0.75	0.29
		0.25	0.71

Note: This table presents calibrated values in the baseline model – the version with heterogeneous sectors and heterogeneous technology shocks. The two I-O matrices (at the bottom) display the fraction of total materials used in each sector that comes from each of the other sectors. Rows represent production (output), and columns consumption (input). For instance, the Canadian goods sector spends 20% of its total material expenditures on materials from the service sector.

Table 2: Results – Symmetric model

	Cross-country correlation	*All foreign shocks*	*Decomposition of shocks*			
			ε_G	ε_S	ε_G^F	ε_S^F
GDP	25.3	8.5	45.8	45.8	4.2	4.2
Hours	29.4	10.0	45.0	45.0	5.0	5.0
Interest	46.8	21.9	39.0	39.0	11.0	11.0
Inflation	35.3	12.5	43.7	43.7	6.3	6.3
Wage	33.2	16.6	41.7	41.7	8.3	8.3

Note: The first column reports cross-country correlations between domestic and foreign variables (multiplied by 100). The second column sums up the percentage share of total variation in domestic variables that is attributed to foreign shocks. Remaining columns decompose total variability in domestic variables to each single source of innovation.

Table 3: Results – Heterogeneous sectors and shocks

	Cross-country correlation	*All foreign shocks*	*Decomposition of shocks*			
			ε_{A1}	ε_{A2}	ε^F_{A1}	ε^F_{A2}
GDP	71.1	52.4	40.8	6.8	52.2	0.2
Hours	66.3	49.1	27.5	23.4	48.2	0.9
Interest	80.0	65.0	30.4	4.6	64.4	0.5
Inflation	76.4	58.9	38.6	2.6	58.5	0.3
Wage	78.4	65.0	24.9	10.1	64.5	0.5

Note: See Table 2.

Table 4: Results – The dimensions of heterogeneity

	Cross-country correlation	All foreign shocks	Decomposition of shocks ε_G	ε_S	ε_G^F	ε_S^F
		Panel A – Symmetric shocks				
GDP	43.8	27.0	14.1	58.8	25.0	2.0
Hours	30.6	13.9	3.9	82.3	9.4	4.5
Interest	60.3	42.7	12.1	45.2	35.3	7.4
Inflation	64.8	47.1	19.8	33.1	41.5	5.6
Wage	35.4	28.0	6.5	65.5	23.2	4.8
		Panel B – Symmetric trade intensity				
GDP	38.5	15.5	81.2	3.2	15.1	0.4
Hours	52.8	31.1	52.2	16.7	29.8	1.3
Interest	50.6	25.9	72.0	2.2	25.0	0.9
Inflation	41.5	17.4	81.2	1.4	17.1	0.3
Wage	48.5	25.2	68.8	6.0	24.1	1.1
		Panel C – Symmetric price stickiness				
GDP	54.4	36.5	54.0	9.4	36.3	0.2
Hours	47.0	25.3	65.3	9.4	24.7	0.6
Interest	80.4	67.4	24.0	8.6	66.6	0.8
Inflation	66.4	46.9	42.3	10.7	46.4	0.5
Wage	58.9	49.5	43.1	7.4	49.0	0.5
		Panel D – Homogeneous technology				
GDP	74.0	57.6	32.3	10.1	57.5	0.1
Hours	73.7	58.9	21.5	19.6	57.0	1.9
Interest	84.5	72.7	21.6	5.7	71.9	0.7
Inflation	82.0	68.1	28.5	3.4	67.6	0.4
Wage	79.7	69.2	17.9	12.9	68.6	0.6
		Panel E – Homogeneous I-O structure				
GDP	60.1	37.6	52.4	10.0	37.4	0.2
Hours	60.0	39.8	33.9	26.3	38.7	1.1
Interest	71.4	51.8	41.7	6.6	51.0	0.8
Inflation	67.4	45.8	50.4	3.8	45.5	0.3
Wage	67.2	49.8	33.2	17.1	49.0	0.8

Note: See Table 2 for notation and Table 1 for parameter values except for the following: Panel A: $\sigma_G = \sigma_S = 0.0285$. Panel B: export-GDP ratio equal to 0.4 in both sectors. Panel C: $\theta_G = \theta_S = 0.75$. Panel D: $\phi_G = \phi_S = 0.49$. Panel E: $\zeta_G = \zeta_S = 0.5$.