Openness and Optimal Monetary Policy ☆

Giovanni Lombardo[a,*], Federico Ravenna[b]

[a] *European Central Bank*
[b] *HEC Montréal*

Abstract

We show that the composition of international trade has important implications for the optimal volatility of the exchange rate, above and beyond the size of trade flows. Using an analytically tractable small open economy model, we characterize the impact of the trade composition on the policy trade-off and on the role played by the exchange rate in correcting for price misalignments. Contrary to models where openess can be summarized by the degree of home bias, we find that openness can be a poor proxy of the welfare impact of alternative monetary policies. Using input-output data for 25 countries we document substantial differences in the import and non-tradable content of final demand components, and in the role played by imported inputs in domestic production. The estimates are used in a richer small-open-economy DSGE model to quantify the loss from an exchange rate peg relative to the Ramsey policy conditional on the composition of imports. We find that the main determinant of the losses is the share of non-traded goods in final demand.

Keywords: International Trade; Exchange Rate Regimes; Non-tradable Goods; Optimal Policy

---

☆We would like to thank Matteo Cacciatore, Luca Dedola, Margarida Duarte, Bart Hobijn, Sylvain Leduc, Phillip McCalman and Dan Wilson for helpful comments and suggestions. Part of this work was prepared while Federico Ravenna was participating in the European Central Bank Visiting Researcher program. Support from the European Central Bank is gratefully acknowledged. The views expressed in this paper do not necessarily reflect those of the European Central Bank.

*Corresponding author.

Email addresses: giovanni.lombardo@ecb.int (Giovanni Lombardo), federico.ravenna@hec.ca (Federico Ravenna)

1. Introduction

The nominal exchange rate is probably the defining variable in open-economy monetary economics. In an economy where trade barriers result in little international exchange of assets and goods, the monetary policymaker can neglect the effects on the nominal exchange rate of its policy at a limited cost in terms of welfare. On the contrary, in a very open economy, exchange rate adjustments are likely to be a key ingredient in the design of the optimal monetary policy response to shocks.

In this paper we argue that the *composition* of international trade flows can affect the policy trade-off faced by the policymaker and the optimal response of the exchange rate to shocks, above and beyond the degree of openness, measured by the *size* of the international trade flows.[1] Our modeling approach allows economies with identical degree of openness to differ in the degree of home bias in the demand for tradable goods, in the share of non-tradables in consumption and investment demand, and in the share of imported intermediates in domestic production.[2] We find that there is no systematic relationship between openness and optimal exchange rate volatility, and discuss how the composition of trade flows impacts the policy trade-off, and the role played by the exchange rate in correcting for price misalignments.

The analysis proceeds as follows. First, we document from input-output tables data that differences in the composition of international trade flows across both industrial and emerging economies are substantial, and provide estimates of the tradable and non-tradable input shares in consumption and investment for 25 countries.

[1] The openness of an economy to trade in goods and services is determined by trade policy and the existence of trade barriers, regardless of the actual amount of trade flows occurring in equilibrium. Our measure of openness correlates optimal policy choices with *observable* trade flows. In our model, openness is determined by preference and technology parameters, which are taken as primitives by the policymaker, and determine steady state trade flows.

[2] A similar emphasis on non-traded goods is also in Corsetti et al. (2008), Dotsey and Duarte (2008) and Duarte and Obstfeld (2008). Devereux and Engel (2007) consider imported intermediate goods in production. Engel and Wang (2010) discuss the importance of durable consumption in explaining the high volatility of imports and exports.

Second, we build a simple, analytically tractable, multi-good model of a small open economy (SOE) with one-period preset prices to illustrate through which channels the composition of imports affects the policy trade-off and the transmission of shocks under alternative policy regimes.

In our model both imported and exported goods are priced in foreign markets, similarly to Mendoza (1995). This set up implies that the terms of trade are independent of policy. Because of the preferences specification, this exogeneity is not important for our analytical results on optimal policy, while it allows us to easily characterize the consequences of exchange rate misalignments in an economy with multiple imported goods. Additionally, our assumption about pricing is appropriate to describe emerging market economies, which typically specialize in the export of few primary commodities, and are normally small players in the world markets. For these countries, terms of trade variations can be considered exogenous.

Finally, we discuss how our results carry over to a more complete model of the economy, including sector-specific capital, imported investment goods, and incomplete financial markets. In this setup, we assess quantitatively the welfare implications of the composition of international trade flows using parameter values estimated from input-output tables.

Our analytical results show that the rate at which the optimal policy trades off inefficiency gaps across sectors depends on the relative weight of each good in the household preferences, but is not directly related to openness, which depends also on the share of imported intermediate inputs in production. Even in the limiting case where the composition of imports does not affect the trade-off, it still affects the welfare cost of a peg through two channels. First, the share of imported intermediates in production affects the optimal volatility of exchange rate movements, for given trade-off. Second, the weight of the inefficiently-priced good in the CPI affects the size of the welfare loss under a peg, for given optimal volatility of the exchange rate.

In our model, a peg is costly because it forces the adjustment in the tradable/non-tradable relative price on the sticky nominal price. This mechanism works through the spill-over of input prices across sectors: since labor is mobile across sectors, *any* change affecting the conditions for efficient production in one sector will spill over to the other sector through changes in nominal wages, resulting in a price misalignment under a peg. This propagation mechanism explains the role of the intermediate imports share: a larger share requires a larger optimal movement in the exchange rate to prevent changes in nominal wages across *all* sectors and inefficient mark-up fluctuations. The intermediate imports share is only relevant if production is asymmetric across sectors. If tradable and non-tradable goods are produced with the same technology, the optimal policy calls for exchange rate stability in response to shocks to imported intermediate prices.

The numerical results confirm that our findings extend to a richer sticky price SOE model. Openness and optimal exchange rate volatility turn out to be close to orthogonal variables. This result holds also if financial markets are incomplete and regardless of the importance of distortions in the pricing of imports or of frictions preventing costless labor mobility across sectors. An exchange rate peg leads to large welfare losses in an economy where the share of imported intermediates in the domestic production input mix is high, and at the same time the bias towards non-tradable goods is high. In an equally open economy importing mainly consumption or investment goods a peg leads only to a modest welfare loss. When estimating the model's preference and technology parameters using OECD input-output tables data for 25 countries, we find that the welfare loss is highly correlated with the share of non-tradable goods in final demand.[3]

Our paper is related to several recent contributions. Friedman (1953) and Mundell (1961) pointed out long ago that, in economies displaying nominal rigidities, nominal exchange rate adjustments are a key ingredient in the efficient response to shocks. A more recent literature recognizes that the optimal volatility of the exchange rate crucially depends on the degree of openness of the economy, which in the simplest models, where all goods are tradable, is inversely related to the degree of home bias in preferences.[4] Our analysis shows that results

[3]In this exercise, our welfare metric is the cost of fixing the exchange rate, relative to the optimal policy. This is a welfare measure that is relevant from the point of view of the policymaker. IMF (2008) reports that 84 countries have either a fixed exchange rate target or rely on a currency board.

[4]Corsetti et al. (2012) highlight the welfare costs and trade-offs brought about by a (real) exchange rate misalignment in open-economy models with nominal rigidities. Corsetti (2006), Sutherland (2005) and Faia and Monacelli (2008) study explicitly the relationship between openness and optimal policy. These authors don't consider richer compositions of international trade and of domestic demand. While focusing on different aspects of optimal policy, also Corsetti et al. (2008), De Paoli (2009a) and Engel (2011) acknowledge the importance of home bias in their results.

from stylized models where home bias and openness are directly related cannot be generalized once the cross-country variation in the composition of imports is taken into account.

Faia and Monacelli (2008) provide a detailed analysis of the impact of home bias on optimal policy in a small open economy model with only tradable goods. They conclude that optimal exchange rate volatility is monotonically decreasing in the degree of openness. Corsetti (2006) shows in a two-country model that exchange rate volatility is optimal whenever there is home bias, even if import prices are preset in local currency, following a local currency pricing framework also used by Devereux and Engel (2003). In the presence of home bias, exchange rate fluctuations allow the policymaker to optimally respond to asymmetric shocks. The relationship between openness - proportional to the degree of home bias - and optimal exchange rate volatility is non-monotonic, although volatility increases for positive degrees of home bias. The existence of several additional goods and the spill-over across sectors of sectoral shocks implies that neither of these results hold in our model.

Duarte and Obstfeld (2008) present a two-country model where the existence of non-traded goods, rather than home bias, generates asymmetry in the way domestic and foreign consumption react to shocks, and result in exchange rate volatility under the optimal policy even in the absence of exchange rate pass-through. As in their work, the existence of non-traded goods in our model implies that the risk-sharing condition depends on the relative price of traded and non-traded goods, generating an incentive for the optimal policymaker to manipulate allocations through the exchange rate. Dotsey and Duarte (2008) examine the role of non-tradables for business cycle correlations in a model similar to ours. They assume a complete input-output structure in the economy, so that final non-tradable goods are an input in domestic production. We have only a partial input-output structure in the model, but parameterize the final demand aggregators using estimates of input shares, rather than final demand shares, so as to account for the shares of final goods production being used as intermediates by other sectors. In this way, our model is more easily comparable with most of the recent open economy macroeconomics literature.

The paper is structured as follows. Section 2 provides empirical results on the role of imported consumption and intermediate goods, and estimates of the tradable and non-tradable goods' shares in final demand for 25 countries. Section 3 develops a one-period preset-price model and derives analytical results concerning the relationship between the composition of international trade flows and optimal monetary policy. Section 4 describes the model used to obtain our numerical results on welfare outcomes. Section 5 concludes.

2. Trade Flows Composition and Tradable Goods Demand across Countries

We document a number of empirical results on the composition of final demand, on the magnitude of imported consumption and investment relative to the size of the domestic economy, and on the role played by imported inputs in domestic production for 25 industrial and emerging economies using input-output tables by the OECD.[5] The final demand share of each component of imports depends on the import share in the tradable basket, and on the share of tradable and non-tradable goods in final demand. Since these shares are separately parameterized in open economy DSGE models with a non-tradable sector, we use the input-output tables to compute estimates of the share of tradable and non-tradable goods in consumption and investment demand.

We estimate the tradable share of demand using an approach similar to that of De Gregorio et al. (1994). For each industry in the input-output tables, we define a tradability measure equal to the sum of exports and imports relative to its gross output. The output from an industry is considered tradable if its tradability measure is above a critical threshold. We consider a 10% threshold, identical across countries.[6]

We measure the content of tradable and non-tradable goods in final demand using symmetric input-output tables at basic prices, where the final dollar demand for a good is reported net of the cost paid to cover local (non-tradable) services. Thus the data allocate the value of the distribution margin for imported goods to the appropriate (non-tradable) industry. Additionally, to account for the intermediate non-tradable (tradable) input content

[5]Our dataset consists of the 2009 edition of the OECD input-output tables. For most of the countries we averaged the results obtained from the two available tables between 2000 and 2005. For Korea, Mexico, New-Zealand and Slovakia only one year was available.

[6]Lombardo and Ravenna (2012) provide a detailed analysis of tradability estimates using input-output data, and report results using a country specific threshold, equal to the tradability measure of the wholesale and retail trade sector (which is assumed to produce non-tradable output) in each country. A 10% threshold is used by De Gregorio et al. (1994) and Betts and Kehoe (2001) and is close to the average tradability measure based on wholesale and retail sector used by Bems (2008).

in the final demand of tradable (non-tradable) goods, we compute tradable input shares - rather than final demand shares - defined as the share of tradable goods embedded in a dollar of final demand throughout the whole production chain. Lombardo and Ravenna (2012) provide details on the computation using input-output tables data.

Table 1 compares the consumption and investment non-tradable input shares across our sample of countries. US and Japan are at the high end of the range, while small open economies, such as Ireland, Belgium and Luxembourg, have consumption non-tradables input shares of around 20%.

Table 1 also summarizes data on openness, imports and demand composition. The data show that there is a remarkable variation both in the export to GDP ratio, a standard measure of trade openness, and in the composition of imports. Not only demand for imports can come from different components of final demand - such as consumption or investment - but countries differ also in the amount of final relative to intermediate goods imported, and in the relative importance of imported intermediates in domestic production. Italy and Portugal, for example, have nearly identical degree of openness, while the share of imported consumption goods in total consumption is nearly twice as large in Portugal (17%) than in Italy (9%), and the ratio of intermediate imports to GDP is equal to 24% in Portugal and 18% in Italy. Five countries rely on imported inputs for a value larger than 40% of GDP. Estonia and Slovakia are the largest importers of intermediates relative to the size of the economy, with a ratio of imported inputs to GDP just below 59%, while the US is at the low end of the range, with a ratio of 7.6%.

Finally, the data reported in Table 1 document a large cross-country variation in the share of tradable investment demand which is not domestically produced. For example, using the data in Table 1 the share of imported investment in total tradable investment results equal to about 22% in Germany and 43% in the Czech Republic. The main factor driving these cross country differences is the share in GDP of imported investment, with a standard deviation of 42%, while the standard deviation for the tradable investment share and the share of investment demand in GDP is respectively equal to 17% and 18%.

3. A Simple Small Open Economy Model with Predetermined Prices

In this section we develop a small open economy version of the model in Corsetti and Pesenti (2001) introducing non-tradable and multiple imported goods. We use the model to derive analytical results on the role of the composition of international trade in determining the optimal volatility of the exchange rate and the cost of an exchange rate misalignment.[7]

The economy produces a non-tradable good (N) and a domestic tradable good (H) using labor and an imported intermediate input. Households' preferences are defined over a basket of tradable (T) and non-tradable goods. The tradable good basket includes two goods: a foreign good (F), that must be imported, and the domestic tradable good. Prices in the N sector and for a fraction of the imported goods are preset one period in advance. All households' consumption is assumed to be non-durable. In order to obtain analytical results we assume log preferences in consumption and Cobb-Douglas aggregators.

We assume that both imported and exported goods are priced in foreign markets. This assumption implies that terms of trade are exogenous, so that the incentive to manipulate the terms of trade is absent in our model. Given our assumptions of log preferences in consumption and Cobb-Douglas aggregators, the terms of trade incentive would be absent even in the case of differentiated tradable goods (Corsetti et al., 2010b). Furthermore, as pointed out by Corsetti et al. (2010b), the literature is still divided about the relevance of this margin in determining optimal monetary policy decisions.

3.1. Households

Households choose labor hours H_t and consumption C_t to maximize expected utility

$$E_t \sum_{i=0}^{\infty} \beta \left[\log \left(C_{t+i} \right) - \frac{H_{t+i}^{1+\eta}}{1+\eta} \right] \tag{1}$$

subject to the period budget constraint

$$P_t C_t + E_t Q_{t+1} B_{t+1} = W_t^H H_t^H + W_t^N H_t^N + \Pi_t + B_t. \tag{2}$$

[7] Our approach is related to a large literature in open economy macroeconomics, including Corsetti and Pesenti (2001), Devereux and Engel (2002), Devereux and Engel (2007), Faia and Monacelli (2008), Galí and Monacelli (2005), Obstfeld and Rogoff (2000), Sutherland (2006) and Sutherland (2005).

where Π_t are profits rebated to the households by firms, B_{t+1} is a portfolio of state-contingent securities ensuring complete financial markets, as in Chari et al. (2002), W_t^H and W_t^N are the wages paid in the non-tradable N and tradable H domestic production sector, and $H_t = H_t^N + H_t^H$. Total consumption C_t is a composite of non-tradable and tradable consumption baskets

$$C_t = C_{N,t}^{\gamma_n} C_{T,t}^{1-\gamma_n}, \tag{3}$$

where, in turn, the non-tradable consumption basket is made up of a continuum of differentiated goods

$$C_{N,t} = \left[\int_0^1 C_{N,t}^{\frac{\varrho-1}{\varrho}}(z) dz \right]^{\frac{\varrho}{\varrho-1}}$$

with $\varrho > 1$. The tradable basket combines domestic and foreign produced goods,

$$C_{T,t} = C_{H,t}^{\gamma_H} C_{F,t}^{1-\gamma_H} \tag{4}$$

with price indexes defined as

$$P_t = \gamma_n^{-\gamma_n} (1-\gamma_n)^{-(1-\gamma_n)} P_{N,t}^{\gamma_n} P_{T,t}^{1-\gamma_n} \tag{5}$$

$$P_{T,t} = \gamma_H^{-\gamma_H} (1-\gamma_H)^{-(1-\gamma_H)} P_{H,t}^{\gamma_H} P_{F,t}^{1-\gamma_H} \tag{6}$$

The solution to the household problem implies the following first order conditions:

$$C_{N,t} = \frac{\gamma_n}{1-\gamma_n} \left(\frac{P_{T,t}}{P_{N,t}} \right) C_{T,t} \quad ; \quad C_{H,t} = \frac{\gamma_H}{1-\gamma_H} \left(\frac{P_{F,t}}{P_{H,t}} \right) C_{F,t}$$

$$\frac{W_t^N}{P_t} = H_t^\eta C_t \quad ; \quad \frac{W_t^H}{P_t} = H_t^\eta C_t$$

$$\frac{C_t}{C_t^*} = \kappa \frac{S_t P_t^*}{P_t}$$

where S_t is the nominal exchange rate, κ depends on initial relative consumption and where an asterisk indicates foreign variables. The labor supply optimality conditions imply that the nominal wage W_t is equalized across sectors.

3.2. Non-tradable Sector

A continuum of monopolistically competitive firms indexed by j produces output $Y_{N,t}(j)$using the technology

$$Y_{N,t}\left(j\right) = Z_{N,t}H_{N,t}\left(j\right) \tag{7}$$

where $Z_{N,t}$ is an exogenous productivity shock. The j good price at time t must be set one period in advance, and is denoted by $p_{N,t-1}(j)$. Demand for good j is given by

$$Y_{N,t}\left(j\right) = \left(\frac{p_{N,t-1}\left(j\right)}{P_{N,t}}\right)^{-\varrho}\left(\frac{P_{N,t}}{P_t}\right)^{-1}C_t \tag{8}$$

In period t firms choose $p_{N,t}(j)$ to maximize the expected household's dividend

$$E_t\beta\frac{U_{c,t+1}}{P_{t+1}}\left[p_{N,t}\left(j\right) - MC^{nom}_{N,t+1}\right]Y_{N,t+1}\left(j\right), \tag{9}$$

conditional on the nominal marginal cost of production $MC^{nom}_{N,t+1} = Z^{-1}_{N,t+1}W_{t+1}$.

The first order condition implies:

$$p_{N,t} = \frac{\varrho}{\varrho-1}\frac{E_t\frac{U_{c,t+1}}{P_{t+1}}Y_{N,t+1}MC^{nom}_{N,t+1}}{E_t\frac{U_{c,t+1}}{P_{t+1}}Y_{N,t+1}} \tag{10}$$

where we have dropped the firm index since all firms will choose the same optimal price, implying $P_{N,t} = p_{N,t-1}$.

3.3. Domestic Tradable Sector

Technology in this sector requires the use of imported intermediate goods M_t purchased at price $S_tP^*_{M,t}$ as input into production, where S_t denotes the nominal exchange rate:

$$Y_{H,t} = Z_{H,t}H^{\gamma_v}_{H,t}M^{1-\gamma_v}_t. \tag{11}$$

Perfect competition implies that the price $P_{H,t}$ is set equal to the marginal cost of production. Since the H good is perfectly substitutable with goods produced abroad and sold at price

$S_t P^*_{H,t}$, the law of one price and production efficiency require

$$S_t P^*_{H,t} = Z^{-1}_{H,t}(1-\gamma_v)^{-(1-\gamma_v)}\left(\gamma_v\right)^{(-\gamma_v)} W_t^{(\gamma_v)}\left(S_t P^*_{M,t}\right)^{(1-\gamma_v)}. \tag{12}$$

3.4. Foreign Sector

The foreign-produced good F is purchased by a continuum of monopolistically competitive firms in the import sector as an input for production, at price $S_t P^*_{F,t}$. A fraction γ_F presets the price $p_{F,t}$ in local currency one period in advance, while the remaining producers can reset the prices optimally in every period.

Preferences for the goods supplied by the two types of importers are defined by a Cobb-Douglas aggregator, implying the domestic price of the final imported good is

$$P_{F,t} = \gamma_F^{-\gamma_F}\left(1-\gamma_F\right)^{(\gamma_F-1)} P^{\gamma_F}_{s,F,t}\left(\frac{\varrho}{\varrho-1} S_t P^*_{F,t}\right)^{(1-\gamma_F)}. \tag{13}$$

where $P_{s,F,t}$ is the price of the basket of goods supplied by the sticky-price importers, $\frac{\varrho}{\varrho-1} S_t P^*_{F,t}$ is the price charged by the $(1-\gamma_F)$ fraction of importers, and without loss of generality we assume that the optimal mark-up $\frac{\varrho}{\varrho-1}$ in this sector is identical to the one in the non-tradable sector. This specification implies that if $\gamma_F = 0$ the imported final good prices are flexible, implying producer currency pricing (PCP), while if $\gamma_F \in (0,1]$ the pass-through of changes in $S_t P^*_{F,t}$ into changes in $P_{F,t}$ is incomplete in the short run. We will refer to this pricing arrangement as the Local Currency Pricing (LCP) case.

Given the demand for sticky-price imported goods

$$Y_{s,F,t}(j) = \gamma_F\left(\frac{p_{F,t-1}(j)}{P_{s,F,t}}\right)^{-\varrho}\left(\frac{P_{s,F,t}}{P_{F,t}}\right)^{-1} C_{F,t} \tag{14}$$

the price chosen by the j sticky-price importer is

$$p_{F,t} = \frac{\varrho}{\varrho-1}\frac{E_t \frac{U_{c,t+1}}{P_{t+1}} Y_{s,F,t+1} S_{t+1} P^*_{F,t+1}}{E_t \frac{U_{c,t+1}}{P_{t+1}} Y_{s,F,t+1}} = \tag{15}$$

where the firm index j can be dropped since all firms will choose the same optimal price, implying $P_{s,F,t} = p_{F,t-1}$.

3.5. Exogenous Shocks

The logarithm of the exogenous shocks $Z_{N,t}$, $Z_{H,t}$, $P^*_{H,t}$, $P^*_{M,t}$, $P^*_{F,t}$ are assumed to follow first-order autocorrelated stochastic processes, with identical AR(1) coefficient ρ, and innovation of the shock X_t denoted by ε_{X_t}. We assume that (log) foreign nominal consumption $\mu^*_t = P^*_t C^*_t$ follows an AR(1) process.

3.6. The Ramsey Policy

In this section we set up the Ramsey problem and characterize the trade-off across policy objectives, the dynamics of the nominal exchange rate and the welfare outcomes, conditional on the optimal policy. Appendix A provides the mathematical details for the derivation of all results in this section.

3.6.1. First Order Conditions for the Ramsey Plan

The domestic monetary authority solves the problem of a benevolent policymaker maximizing the household's objective function conditional on the first order conditions of the competitive equilibrium. This approach provides the (constrained efficient) equilibrium sequences of endogenous variables solving the Ramsey problem.[8] We assume that the steady-state mark-up is eliminated through subsidies.

Exploiting the result that under our assumptions equilibrium employment is independent of policy, and similarly to Corsetti and Pesenti (2001), we can express the welfare function in terms of nominal consumption $\mu_t \equiv P_t C_t$, and the price level. The Ramsey problem can then be written as:

$$\max_{\mu_t, P_t} E_0 \sum_{t=0}^{\infty} \beta^t \left[\log \left(\frac{\mu_t}{P_t} \right) \right] + t.i.p. \tag{16}$$

subject to

$$P_t = \kappa_N P_{N,t}^{\gamma_n} \left(\kappa_H \left(\frac{\mu_t}{\kappa \mu^*_t} P^*_{H,t} \right)^{\gamma_H} P_{F,t}^{1-\gamma_H} \right)^{1-\gamma_n} \tag{17}$$

[8] For a discussion of the Ramsey approach to optimal policy, see Schmitt-Grohé and Uribe (2004), Benigno and Woodford (2006), Khan et al. (2003), Coenen et al., 2009.

where

$$P_{F,t} = \kappa_F \left(\frac{\mu_t}{\kappa \mu_t^*} P^*_{F,t} \right)^{(1-\gamma_F)} \left(E_{t-1} \frac{\mu_t}{\kappa \mu_t^*} P^*_{F,t} \right)^{\gamma_F} \quad (18)$$

$$P_{N,t} = E_{t-1} Z_{N,t}^{-1} H_t^{\eta} \mu_t \quad (19)$$

κ_F, κ_N, κ_H are convolutions of preferences and technology parameters, $\frac{\mu_t}{\kappa \mu_t^*} = S_t$ and $t.i.p.$ indicates terms independent of policy.

The first order condition for the Ramsey problem can be written in terms of a trade-off across the two variables $\xi_{N,t}$ and $\xi_{F,t}$:

$$1 = (1 - \Gamma)\, \xi_{N,t} + \Gamma \xi_{F,t} \quad (20)$$

where

$$\Gamma \equiv \frac{\gamma_F (1-\gamma_H)(1-\gamma_n)}{\gamma_n + \gamma_F (1-\gamma_H)(1-\gamma_n)}$$

$$\xi_{N,t} \equiv \frac{Z_{N,t}^{-1} W_t}{E_{t-1}\left(Z_{N,t}^{-1} W_t \right)} \equiv \frac{MC_{N,t}^{nom}}{p_{N,t}}$$

$$\xi_{F,t} \equiv \frac{S_t P^*_{F,t}}{E_{t-1}\left(S_t P^*_{F,t} \right)} \equiv \frac{MC_{F,t}^{nom}}{p_{F,t}}$$

The variables $\xi_{N,t}$ and $\xi_{F,t}$ are the real marginal cost in the non-tradable and in the sticky-price import sector. Since the real marginal cost is also equal to the inverse of the mark-up, it also measures the deviation from efficiency caused by price stickiness.

Under flexible prices the inefficiency wedges are equal to 1. It is easy to check that this value satisfies the first order condition.[9] In general, the policymaker will not be able to replicate the flexible price allocation when prices in the non-tradable and import sector are sticky.

The first order condition (20) describes how the policymaker should trade off deviations from the profit-maximizing mark-up in the F and N sectors to keep welfare at the optimal

[9]This result is consistent with Faia and Monacelli (2008),where under log-preferences in consumption and Cobb-Douglas aggregators, the first best in a SOE with complete markets and sticky prices coincides with the flexible price allocation.

level. Consistently with results in the literature,[10] if preferences are such that only one nominal rigidity is relevant for the equilibrium, no trade-off across inefficiency wedges exists. The Ramsey policy calls then for completely stabilizing the single inefficient mark-up, and is able to replicate the flexible-price allocation. This will occur if households purchase exclusively non-tradable goods ($\gamma_n = 1$), domestically produced goods ($\gamma_H = 1$), or if the share of LCP importers is nil ($\gamma_F = 0$) - in which case the weight Γ on the F sector markup stabilization objective is zero - and will also occur if household purchase exclusively tradable goods ($\gamma_n = 0$) - in which case the weight $(1 - \Gamma)$ on the N sector markup stabilization objective is zero.[11]

The trade-off across the two objectives depends on the parameters $\gamma_n,\ \gamma_H,\ \gamma_F$, but not on the share of imported intermediates in domestic production, γ_v. To examine the role of the weights in the trade-off, it is useful to assume that the share of LCP importers γ_F is equal to 1. Then,

$$\Gamma \;=\; 1 - \frac{\gamma_n}{\gamma_n + (1-\gamma_H)(1-\gamma_n)} \tag{21}$$

Eq. (21) shows that a fall in γ_H results in an increase in the weight Γ on the F sector markup. Since a larger share of imported F goods (and a corresponding smaller share of H goods) in the tradable basket increase the welfare cost of inefficient fluctuations in $\xi_{F,t}$, the optimal policy calls for an increase in the relative weight given to this objective. Similarly, an increase in γ_n results in a decrease of the weight Γ, and an increase in the weight $(1-\Gamma)$ given to movements in $\xi_{N,t}$.

[10] See for example Corsetti and Pesenti (2005), Corsetti and Pesenti (2001), Corsetti (2006), Corsetti et al. (2012), Corsetti et al. (2010b), Devereux and Engel (2003), Devereux and Engel (2007), Smets and Wouters (2002), Duarte and Obstfeld (2008) and Faia and Monacelli (2008).

[11] For $\gamma_F = 0$ and $\gamma_n = 0$ the Ramsey allocation is implemented respectively by the policy $S_t = \left(Z_{N,t}^{-1} H_t^{\eta} P_t^{*} C_t^{*}\right)^{-1} E_{t-1}\left(Z_t^{-1} H_t^{\eta} P_t^{*} C_t^{*}\right)$ and $S_t = P_{F,t}^{*-1} E_{t-1}\left(P_{F,t}^{*}\right)$. The allocation can also be implemented by the policies $S_t = \left(Z_{N,t}^{-1} H_t^{\eta} \mu_t^{*}\right)^{-1}$ and $S_t = P_{F,t}^{*-1}$ respectively, which correspond to price stability in P_N and p_F, but do not imply an iid process for S_t, as we have assumed in the text. Since with preset prices firms fully incorporate the forecastable component of variables in their pricing decision, price stability is not necessary to implement the flexible price allocation.

3.6.2. Optimal Exchange Rate Volatility and the Welfare Cost of a Peg

Using the first order conditions for the Ramsey problem, this section provides the optimal policy implications for exchange rate volatility and the welfare cost of an exchange rate peg.

As there is no closed form solution when $\gamma_F \neq 0$ and $\gamma_n \neq 0$, we assess welfare up to the second order of accuracy. To this aim we obtain the second-order accurate law of motion for S_t. Write eq. (20) as:

$$1 = (1-\Gamma)\frac{Z_{N,t}^{-1}\left(P_{H,t}^{*} Z_{H,t}\left(P_{M,t}^{*}\right)^{-(1-\gamma_v)}\right)^{\frac{1}{(\gamma_v)}} S_t}{E_{t-1}\left(Z_{N,t}^{-1}\left(Z_{H,t}\left(P_{M,t}^{*}\right)^{-(1-\gamma_v)}\right)^{\frac{1}{(\gamma_v)}} S_t\right)} + \Gamma\frac{S_t P_{F,t}^{*}}{E_{t-1}\left(S_t P_{F,t}^{*}\right)}.$$

The first-order accurate solution for the exchange rate is

$$\tilde{S}_t = -(1-\Gamma)\left(-\varepsilon_{Z_{N,t}} + \frac{1}{\gamma_v}\left(\varepsilon_{P_{H,t}^{*}} + \varepsilon_{Z_{H,t}} - (1-\gamma_v)\varepsilon_{P_{M,t}^{*}}\right)\right) - \Gamma\varepsilon_{P_{F,t}^{*}}, \qquad (22)$$

where a tilde denotes log deviations. The second order accurate solution is given by

$$\begin{aligned}\tilde{S}_t \;=\; & -(1-\Gamma)\left(-\varepsilon_{Z_{N,t}} + \frac{1}{\gamma_v}\left(\varepsilon_{P_{H,t}^{*}} + \varepsilon_{Z_{H,t}} - (1-\gamma_v)\varepsilon_{P_{M,t}^{*}}\right)\right) - \Gamma\varepsilon_{P_{F,t}^{*}} \\ & -\frac{(1-\Gamma)\Gamma}{2}\left[\tilde{X}_t^2 + \tilde{P}_{F,t}^{*2} - 2\tilde{X}_t\tilde{P}_{F,t}^{*} - E_{t-1}\left(\tilde{X}_t^2 + \tilde{P}_{F,t}^{*2} - 2\tilde{X}_t\tilde{P}_{F,t}^{*}\right)\right]\end{aligned}$$

where $\tilde{X}_t \equiv -\tilde{Z}_{N,t} + \frac{1}{\gamma_v}\left(\tilde{P}_{H,t}^{*} + \tilde{Z}_{H,t} - (1-\gamma_v)\tilde{P}_{M,t}^{*}\right)$.[12]

Inspection of the equations describing the dynamics of the exchange rate under the optimal policy shows that the optimal exchange rate response to shocks is i.i.d., that is $E_{t-1}(\tilde{S}_t) = 0$. The intuition is as follows. Under one-period preset prices, the economy can revert to the efficient equilibrium one period after the shock. The policymaker only needs to adjust the exchange rate when an unexpected shock affects the economy, since firms can set the optimal price in response to expected shocks. Therefore, the exchange rate needs to depart from the steady-state only on impact, and to revert to the steady state once prices

[12] Note that variables entering linearly in the expressions for $\widetilde{S}_t$ are evaluated at second-order of accuracy, while variables entering as squares or cross-products are evaluated at first-order of accuracy (see Lombardo and Sutherland, 2007).

will be able to adjust to their efficient value (i.e. absent further shocks).

It is instructive to discuss the optimal exchange rate dynamics derived in eq. (22) together with the welfare outcome under the optimal policy. The welfare gain of adopting the optimal policy, relative to an exchange rate peg, is

$$\begin{aligned} \mathcal{W}_0^{optimal} - \mathcal{W}_0^{peg} &= \frac{1}{2}\left\{\gamma_n\left(1-\Gamma\right)\sigma_N^2 + \right. \\ &+\gamma_n\left(1-\Gamma\right)\frac{1}{\left(\gamma_v\right)^2}\left[\sigma_H^{2*}+\sigma_H^2+(1-\gamma_v)^2\sigma_M^{*2}\right]+ \\ &\left.+\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\Gamma\sigma_F^{*2}\right\} \end{aligned} \tag{23}$$

where $\sigma_j^2 \equiv E\varepsilon_j^2$.

It is clear from this expression that the welfare gain depends on two sets of parameters: the variance of the exogenous processes, and the parameters governing preferences, technology and pass-through of the exchange rate. Eqs. (22) and (23) show the share of imported intermediate inputs $(1-\gamma_v)$, while irrelevant for the trade-off, plays an important role for the optimal volatility of the exchange rate, and consequently for the welfare cost of deviating from it. The larger the share $(1-\gamma_v)$, the larger are the welfare costs of fixing the exchange rate, if the economy is hit by either the domestic tradable shock, $\varepsilon_{H,t}$, the foreign tradable shock, $\varepsilon_{H,t}^*$ or the shock to the imported intermediate goods, $\varepsilon_{M,t}^*$, other things equal and for all values of the other parameters. The share of of non-tradable goods increases the cost of the peg for the same set of shocks plus the non-tradable shock, other things equal and for all values of the other parameters. It decreases the cost of the peg for the shock to imported goods, $\varepsilon_{F,t}^*$. The impact on the cost from pegging the exchange rate of γ_H goes in the same direction as for γ_n, while the share of LCP producers, γ_F, has an opposite effect relative to γ_n.

The interpretation of eqs. (22) and (23) is facilitated by assuming that the share of LCP importers γ_F is equal to 1. In this case, the relative weight in the optimal trade-off equation is given by eq. (21). The welfare cost of a peg, relative to the optimal policy, is equal to

$$
\begin{aligned}
\mathcal{W}_0^{optimal} - \mathcal{W}_0^{peg} \quad = \quad & \frac{1}{2}\left\{\frac{\gamma_n^2}{\gamma_n + (1-\gamma_H)(1-\gamma_n)}\sigma_N^2 + \right. \\
& + \frac{\gamma_n^2}{\gamma_n + (1-\gamma_H)(1-\gamma_n)}\left(\frac{1}{\gamma_v}\right)^2 \left[\sigma_H^{2*} + \sigma_H^2 + (1-\gamma_v)^2\sigma_M^{*2}\right] + \quad (24) \\
& \left. + \left[(1-\gamma_H)\left(1-\gamma_n\right)\right]^2 \frac{1}{\gamma_n + (1-\gamma_H)(1-\gamma_n)}\sigma_F^{*2}\right\}.
\end{aligned}
$$

Consider the impact of a fall in γ_H on the welfare measure $W_0^{optimal} - W_0^{peg}$. A larger share of imported F goods (and a corresponding smaller share of H goods) in the tradable basket increase the welfare cost of inefficient fluctuations in $\xi_{F,t}$. Since stabilizing $\xi_{F,t}$ in response to shocks to the foreign price $P_{F,t}^*$ calls for accommodating the foreign price fluctuations through movements in the nominal exchange rate S_t, as shown in eq. (22), the welfare cost of a peg increases.

The direct effect of the fall in γ_H on the welfare measure is summarized by the third term of eq. (24). The first two terms of eq. (24) summarize instead the indirect effect of the fall in γ_H on welfare, and they lead to a *decrease* in the cost of pegging the exchange rate. First, note that if the share of value added in domestic production γ_v is equal to 1, the first two terms of eq. (24) share the same weight, and the volatilities σ_N^2, σ_H^{2*}, σ_H^2 enter symmetrically in the welfare measure. Then, the cost of an exchange rate peg is smaller as γ_H falls since the optimal policy calls for smaller volatility in S_t when accommodating shocks to $Z_{N,t}$, $Z_{H,t}$, $P_{H,t}^*$ whenever the weight on the objective $\xi_{F,t}$ increases in the trade-off. Changes in S_t - as shown in eq. (22) - are needed to ensure that the markup $\xi_{N,t}$ is stabilized while at the same time ensuring that the cross-sector efficient production conditions are met. Since movements in S_t to stabilize $\xi_{N,t}$ indirectly result in movements in $\xi_{F,t}$ even if the foreign price $P_{F,t}^*$ is stable, a lower γ_H leads to a larger volatility in $\xi_{N,t}$ and a correspondingly lower volatility in S_t through the first two terms of eq. (24).

3.7. The Role of Openness

In this section we discuss how openness affects the optimal policy, and the role of exchange rate volatility in implementing the optimal policy.

3.7.1. Openness and Policy Trade-off

Our first result is that openness need not be correlated with the trade-off faced by the policymaker. Openness is governed by three parameters: the share of imported inputs in the production of tradable goods $(1-\gamma_v)$, the share of non-tradable goods in consumption γ_n, and the degree of home bias γ_H in the consumption of tradable goods. Yet the parameter γ_v does not enter into the equation (20) describing how to trade off the inefficiency wedges, as the relative weight of the two inefficient sectors is independent of this parameter. Thus two economies with different degree of openness may find that the optimal policy calls for trading off distortions at an identical rate.

Our second result is that the composition of imports can affect the welfare cost of alternative policies regardless of whether it affects the trade-off. This result can be easily illustrated in the case of $\gamma_F = 0$. If pricing in the import sector is efficient $(\xi_{F,t} = 1)$, the first order condition (20) calls for setting $\xi_{N,t} = 1$, regardless of the share of imported intermediates in production, of the non-tradable goods share, or of the home bias in consumption. In this case, the optimal exchange rate is given by

$$\tilde{S}_t = \left(\varepsilon_{Z_{N,t}} - \frac{1}{\gamma_v}\left(\varepsilon_{P^*_{H,t}} + \varepsilon_{Z_{H,t}} - (1-\gamma_v)\varepsilon_{P^*_{M,t}}\right)\right)$$

implying that the share of imported intermediates γ_v directly affects optimal exchange rate volatility. Moreover, since the welfare cost $\mathcal{W}_0^{optimal} - \mathcal{W}_0^{peg}$ depends both on the optimal exchange rate volatility, and on the size of the sectors with nominal rigidities, both the parameters γ_v and γ_n will affect the welfare cost of choosing a fixed exchange rate policy.

3.7.2. Openness and Optimal Exchange Rate Volatility

The role of exchange rate movements in achieving the optimal allocation can be illustrated by examining how shocks affect the inefficiency wedges in the economy.

The propagation of shocks and relative price misalignments The Ramsey policy uses movements in the nominal exchange rate to smooth out inefficient movements in mark-ups. Wage equalization is the key propagation mechanism of shocks across sectors. Consider the case when the only nominal rigidity is in the N sector. The Ramsey policy calls for completely stabilizing $\xi_{N,t}$. Under a peg, eq. (12) implies that in response to a shock $P^*_{H,t}$, $Z_{H,t}$ or $P^*_{M,t}$ the nominal wage must change. This leads to a corresponding increase in the wage in the N sector. An increase in W_t will lead to a deviation of $\xi_{N,t}$ from its constant optimal value. Similarly, a shock to $Z_{N,t}$ would require inefficient fluctuations in $\xi_{N,t}$ under a peg, since the price $p_{N,t-1}$ is predetermined and the wage is set at the level required to meet the H sector profit maximization condition (12).

The Ramsey policy prevents movements in W_t, which would result through equations (10) and (12) in a misalignment of the relative price P_{Ht}/P_{N_t} from its efficient level. Equation (22) shows that (to first order) the optimal response to a positive technology shock in the non-tradable goods sector consist of a *depreciation* of the nominal exchange rate. Under flexible prices, a positive technology shock in the non-tradable goods sector would bring about a fall in the price of non-traded goods relative to other goods. A depreciation of the nominal exchange rate provides the same relative price adjustment: all other goods will become more expensive relative to the non-traded good. In the absence of other shocks and with no LCP producers, the optimal exchange rate response would be to exactly offset the technology shock. On the other hand, if a trade-off is present, the adjustment is not 1-to-1 but 1-to-$(1-\Gamma)$. This is due to the fact that, in the presence of LCP producers, an adjustment of the exchange rate will generate volatility in the import sector mark-up, resulting in a loss of efficiency.[13]

The role of imported intermediate goods The share of intermediate imports in the $H-$sector production affects the size of the optimal exchange rate adjustment. In the cases when the Ramsey policy calls for completely stabilizing $\xi_{N,t}$, the exchange rate would be set to completely offset the impact of any change in $P^*_{H,t}$, $Z_{H,t}$ or $P^*_{M,t}$ on the nominal wage W_t. This would in turn prevent fluctuations in $\xi_{N,t}$ resulting from a change in W_t

[13] We have assumed that there are no intermediate goods in the production of non-traded goods. Nevertheless, we can see that the presence of intermediate goods in the production of non-traded goods would make the cost of imported materials increase following a depreciation, hence partially offsetting the downward pressure on costs exerted by the gains in total factor productivity. A depreciation would hence make the inefficiency wedge $\xi_{N,t}$ open by less, thus requiring a milder intervention by the policymaker.

spilling-over across sectors.[14] The required adjustment depends on γ_v, as can be seen by taking a log-linear approximation to eq. (12):

$$\tilde{S}_t - \widetilde{W}_t = -\frac{1}{\gamma_v}\widetilde{Z}_{H,t} - \frac{1}{\gamma_v}\widetilde{P}^*_{H,t} + \frac{1-\gamma_v}{\gamma_v}\widetilde{P}^*_{M,t}$$

A smaller γ_v, or a larger share of imported intermediates in production, will require optimally a larger adjustment in the nominal exchange rate. As a consequence, the welfare cost of a peg increases as γ_v falls, as shown by eq. (23). The optimal response to an unexpected increase of the price of imported intermediates $P^*_{M,t}$ calls for a *depreciation* of the exchange rate, so to leave wages unchanged. As for shocks in the domestically produced traded good, either due to changes in technology $Z_{H,t}$ or to fluctuations in the international price $P^*_{H,t}$, the optimal response of the exchange rate consists in an *appreciation*. The logic is symmetric to the case of shocks in the non-traded goods sector: an appreciation can fully offset the impact of the unexpected change of $P^*_{H,t}$ or $Z_{H,t}$ on the nominal wage, and thus on $\xi_{N,t}$, by respectively keeping the domestic currency price $P_{H,t}$ constant, or by lowering it to increase the real wage of workers in sector H. Fully offsetting the shock will be optimal only if the share of intermediate imports in production is equal to zero. Additionally, in the presence of LCP producers, the exchange rate adjustment has to trade-off the fact that the efficiency wedge in the import sector will be affected.

The role of asymmetric shocks In our model, the existence of imported intermediates affects the optimal policy and welfare only if they enter asymmetrically in the production sectors H and N. Under the optimal policy, the exchange rate must move to prevent relative price misalignments across consumption goods, which are the result of shocks affecting asymmetrically each sector. If relative prices do not need to change, a fixed exchange rate can implement the optimal allocation.

This can be easily seen in the case the Ramsey policy calls for completely stabilizing $\xi_{N,t}$.

[14]In an online appendix, we extend the numerical analysis to the case of frictions in the labor market that break the equality of wages across sectors. As expected, the results are quantitatively affected, since wages in the two sectors adjust only partially to shocks. We establish numerically that our conclusions on the impact of openness on the welfare of alternative policies also hold in a model with quadratic costs of labor reallocation across sectors.

If the share of intermediates in the H sector γ_v is equal to the share in the N sector, denoted $\gamma_{vn,}$ efficiency in production in both sectors implies:

$$\frac{S_t P^*_{H,t}}{P_{N,t}} \xi_{N,t} = \frac{Z_{N,t}}{Z_{H,t}}$$

implying the optimal adjustment to S_t in response to a shock $Z_{N,t}$, $Z_{H,t}$ or $P^*_{H,t}$ is independent of γ_v, $\gamma_{vn.}$ Additionally, the optimal policy calls for no adjustment to S_t in response to a $P^*_{M,t}$ shock. In general, for $(1-\gamma_v)$ and $(1-\gamma_{vn})$ different from zero, the efficiency wedge in the non-traded sector $(\xi_{N,t})$ can be rewritten as

$$\xi_{N,t} \equiv \frac{Z^{-1}_{N,t} \left(H^{\eta}_t \mu^*_t\right)^{\gamma_{vn}} \left(P^*_{M,t}\right)^{1-\gamma_{vn}} S_t}{E_{t-1}\left(Z^{-1}_{N,t} \left(H^{\eta}_t \mu^*_t\right)^{\gamma_{vn}} \left(P^*_{M,t}\right)^{1-\gamma_{vn}} S_t\right)}.$$

The optimal exchange rate policy is then

$$S_t = \frac{E_{t-1}\left(Z^{-1}_{N,t} \left(H^{\eta}_t \mu^*_t\right)^{\gamma_{vn}} \left(P^*_{M,t}\right)^{1-\gamma_{vn}}\right)}{Z^{-1}_{N,t} \left(H^{\eta}_t \mu^*_t\right)^{\gamma_{vn}} \left(P^*_{M,t}\right)^{1-\gamma_{vn}}}.$$

where $\left(H^{\eta}_t \mu^*_t\right)^{\gamma_{vn}} = G_t \left(P^*_{M,t}\right)^{\frac{-(1-\gamma_v)}{\gamma_v}\gamma_{vn}}$ and G_t is a convolution of exogenous variables. If $\gamma_{vn} = \gamma_n$, both the denominator and the numerator will be independent of $P^*_{M,t}$.

Finally, the optimal response to an increase of the price of foreign goods $P^*_{F,t}$ consists of an *appreciation* of the exchange rate. As for this shock, the optimal response as well as the cost of pegging the exchange rate are independent of the share of imported intermediates in production. Except for a polar case in which $\Gamma = 1$, the response of the exchange rate is less than 1-to-1 to allow for the fact that the exchange rate adjustment will also affect the efficiency wedge in the non-tradable sector, through its effect on the domestically produced tradable sector price $P_{H,t}$ and, hence, on wages in all sectors.

Optimal Exchange Rate Volatility and Home Bias A number of papers investigate the relationship between optimal exchange rate volatility and the degree of openness, in models where all goods are tradable. In these models, the home bias parameter fully characterizes openness. Faia and Monacelli (2008) find that exchange rate volatility is (monotonically) increasing in the degree of home-bias, and thus decreasing in openness.

Note that in our model

$$\sigma^2_{\tilde{S}_t} = (1-\Gamma)^2 \left(\sigma^2_{Z_{N,t}} + \frac{1}{\gamma_v^2} \left(\sigma^2_{P^*_{H,t}} + \sigma^2_{Z_{H,t}} + (1-\gamma_v)^2 \sigma^2_{P^*_{M,t}} \right) \right) + \Gamma^2 \sigma^2_{P^*_{F,t}}. \tag{25}$$

As the home bias γ_H increases, the weight of the variance of the shocks in the first term on the right-hand-side of the equation increases, while the weight of the variance of the shocks $P^*_{F,t}$ decreases. Therefore the sign of the correlation between γ_H and $\sigma^2_{\tilde{S}_t}$ is ambiguous, and is more likely to be negative if γ_v is large.

Moreover, eq. (25) shows that the link between openness and optimal exchange rate volatility depend on *all* the parameters determining the composition of imports, through the term Γ, even conditionally on a specific shock.

4. Results in a Parameterized Model with Capital and Staggered Price Adjustment

This section expands the simple framework of Section 3 to provide a model that can be parameterized using macroeconomic and trade data, and used to assess quantitatively the impact of the composition of trade flows on policy choices and welfare outcomes.

We assume CES aggregators for preferences and technologies, introduce sector-specific capital, incomplete financial markets, and staggered price adjustment in place of one-period preset prices. This generalization implies that the Ramsey policymaker has an incentive to manipulate the nominal exchange rate because of its impact on the relative price of tradable and non-tradable goods.

We maintain our assumption that all tradable goods are priced in international markets, so that the interpretation of the trade-offs in the stylized model of Section 3 carries over to the numerical analysis. This pricing assumption is well suited for emerging market economies that produce, and export, commoditized goods. Additionally, our assumption is consistent with the implications for nominal variables of the Balassa-Samuelson effect in a small open economy model (see Ravenna and Natalucci (2008)).

Details on the optimality and market-clearing conditions are in Appendix B.

4.1. Model Setup

4.1.1. Consumption, Investment, and Price Composites

Household preferences are defined over the index C_t, a composite of non-tradable and tradable good consumption, $C_{N,t}$ and $C_{T,t}$ respectively:

$$C_t = \left[(\gamma_{cn})^{\frac{1}{\rho_{cn}}} (C_{N,t})^{\frac{\rho_{cn}-1}{\rho_{cn}}} + (1-\gamma_{cn})^{\frac{1}{\rho_{cn}}} (C_{T,t})^{\frac{\rho_{cn}-1}{\rho_{cn}}} \right]^{\frac{\rho_{cn}}{\rho_{cn}-1}} \tag{26}$$

where $0 \leq \gamma_{cn} \leq 1$ is the share of the N good and $\rho_{cn} > 0$ is the elasticity of substitution between N and T goods. The tradable consumption good is a composite of home and foreign tradable goods, $C_{H,t}$ and $C_{F,t}$, respectively:

$$C_{T,t} = \left[(\gamma_{ch})^{\frac{1}{\rho_{ch}}} (C_{H,t})^{\frac{\rho_{ch}-1}{\rho_{ch}}} + (1-\gamma_{ch})^{\frac{1}{\rho_{ch}}} (C_{F,t})^{\frac{\rho_{ch}-1}{\rho_{ch}}} \right]^{\frac{\rho_{ch}}{\rho_{ch}-1}} \tag{27}$$

where $0 \leq \gamma_{ch} \leq 1$ is the share of the H good and $\rho_{ch} > 0$ is the elasticity of substitution between H and F goods. The non-tradable consumption good N is an aggregate defined over a continuum of differentiated goods:

$$C_{N,t} = \left[\int_0^1 C_{N,t}^{\frac{\varrho-1}{\varrho}}(z)dz \right]^{\frac{\varrho}{\varrho-1}} \tag{28}$$

with $\varrho > 1$. Define P_t^c, $P_{T,t}^c$, and $P_{N,t}$ as the consumer price index (CPI), the price index for T consumption goods, and the price index for N consumption goods, respectively. The terms of trade for consumption and intermediate imports, and the consumption-based (internal) real exchange rate are defined respectively as $\frac{P_{F,t}}{P_{H,t}}$, $\frac{P_{M,t}}{P_{H,t}}$ and $\frac{P_{T,t}^c}{P_{N,t}}$.

Investment in the non-tradable and domestic tradable sector I_t^N, I_t^T is defined in a similar manner - a composite of N, H, and F goods. However, we assume that the share and elasticity parameters $\gamma_{in}, \gamma_{ih}, \rho_{in}, \rho_{ih}$, may differ from those of the consumption composites.

4.1.2. Households

Consider a cashless economy where the preferences of the representative household are given by

$$V = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ D_t(\ln C_t) - \ell \frac{(H_t)^{1+\eta_L}}{1+\eta_L} \right\} \tag{29}$$

where D_t is an exogenous preference shock, η_L is the inverse of the labor supply elasticity and H_t is the total supply of labor hours, defined as $H_t = H_t^N + H_t^H$. Let B_t (B_t^*) denote holdings of discount bonds denominated in domestic (foreign) currency, v_t (v_t^*) the corresponding price, R_t^N (R_t^H) the real return to capital that is rented to firms in the N (H) sector, P_t^i the investment basket price index, and T_t government lump-sum taxes. The household's budget constraint is then given by

$$P_t^c C_t + S_t B_t^* v_t^* + B_t v_t + P_t^i I_t^N + P_t^i I_t^H = W_t^H H_t^H + W_t^N H_t^N + \tag{30}$$

$$S_t B_{t-1}^* + B_{t-1} + P_{N,t} R_t^N K_{t-1}^N + P_{H,t} R_t^H K_{t-1}^H + \Pi_t$$

Capital in each sector can be accumulated according to the laws of motion:

$$K_t^N = \Phi\left(\frac{I_t^N}{K_{t-1}^N}\right) K_{t-1}^N + (1-\delta) K_{t-1}^N \tag{31}$$

$$K_t^H = \Phi\left(\frac{I_t^H}{K_{t-1}^H}\right) K_{t-1}^H + (1-\delta) K_{t-1}^H \tag{32}$$

We assume that installed capital, contrary to labor, is sector-specific. Capital accumulation incurs adjustment costs, with $\Phi'(\bullet) > 0$ and $\Phi''(\bullet) < 0$.

4.1.3. Firms

Non-tradable (N) Sector. The non-tradable sector is populated by a continuum of monopolistically competitive firms owned by households. Each firm $z \in [0,1]$ combines an imported intermediate good, $M_{N,t}$, and domestic value added, $V_{N,t}$ according to the production function:

$$Y_{N,t}(z) = \left[(\gamma_{nv})^{\frac{1}{\rho_{nv}}} (V_{N,t}(z))^{\frac{\rho_{nv}-1}{\rho_{nv}}} + (1-\gamma_{nv})^{\frac{1}{\rho_{nv}}} (M_{N,t}(z))^{\frac{\rho_{nv}-1}{\rho_{nv}}}\right]^{\frac{\rho_{nv}}{\rho_{nv}-1}} \tag{33}$$

Domestic value added is produced using labor and sector-specific capital as inputs:

$$V_{N,t}(z) = A_t^N [K_{t-1}^N(z)]^{\alpha_n} [H_t^N(z)]^{1-\alpha_n}$$

where A_t^N is an exogenous productivity shock. The domestic currency price of the imported intermediate good is given by $P_{M,t} = S_t P_{M,t}^*$ where $P_{M,t}^*$ follows an exogenous stochastic processes. Given the first order conditions for factor demands and the aggregate demand schedule $Y_{N,t}(z) = \left[\frac{P_{N,t}(z)}{P_{N,t}}\right]^{-\varrho} (C_{N,t}+I^H_{N,t}+I^N_{N,t})$, firm z maximizes expected discounted profits by choosing the optimal price $P_{N,t}(z)$. We assume firms are able to optimally reset the price with probability $(1-\vartheta)$ in each period, following the Calvo (1983) pricing mechanism. Non-resetting firms satisfy demand at the previously posted price. Aggregation over the N sector producers gives the standard new Keynesian forward-looking price adjustment equation for non-tradable good inflation.

Domestic Tradable (H) Sector. The tradable good H is produced both at home and abroad in a perfectly competitive environment, where the law of one price holds:

$$P_{H,t} = S_t P^*_{H,t} \tag{34}$$

The price for the foreign-produced H good $P^*_{H,t}$ follows an exogenous stochastic process. Domestic producers combine an imported intermediate good, $M_{H,t}$, and domestic value added, $V_{H,t}$, according to the production function:

$$Y_{H,t} = \left[(\gamma_v)^{\frac{1}{\rho_v}} (V_{H,t})^{\frac{\rho_v-1}{\rho_v}} + (1-\gamma_v)^{\frac{1}{\rho_v}} (M_{H,t})^{\frac{\rho_v-1}{\rho_v}}\right]^{\frac{\rho_v}{\rho_v-1}} \tag{35}$$

Domestic value added is produced using labor and sector-specific capital as inputs:

$$V_{H,t} = A^H_t \left(K^H_{t-1}\right)^{\alpha_h} \left(H^H_t\right)^{1-\alpha_h} \tag{36}$$

where A^H_t is an exogenous productivity shock.

4.1.4. Foreign Sector

We assume that the foreign-produced good F is purchased by a continuum of monopolistically competitive firms in the import sector as an input for production. Each firm z can costlessly differentiate the imported good X_F to produce a consumption good $C_F(z)$ and an investment good $I_F(z)$ using the production technology $Y_F(z) = X_F(z)$, where $X_F(z)$ denotes the amount of input imported by firm z. The nominal marginal cost of producing one unit of output is defined as $MC^{F,nom}_t(z) = S_t P^*_{F,t}$ where $P^*_{F,t}$ is the foreign-currency price of X_F and follows an exogenous stochastic process. The producer faces an aggregate demand schedule given by:

$$Y_{F,t}(z) = \left[\frac{P_{F,t}(z)}{P_{F,t}}\right]^{-\varrho} (C_{F,t} + I_{F,t}^H + I_{F,t}^N)$$

where $Y_{F,t}(z) = C_{F,t}(z) + I_{F,t}^H(z) + I_{F,t}^N(z)$. The domestic-currency price $P_F(z)$ is set by solving an optimal pricing problem symmetrical to the one solved by firms in the N sector, following Calvo (1983). The state-independent probability of resetting the price at every period t is equal to $(1 - \vartheta_F)$. As in Monacelli (2005), this production structure generates deviations from the law of one price in the short run, while asymptotically the pass-through from the price of the imported good to the price of the consumption and investment basket F is complete. We will refer to this pricing arrangement as the Local Currency Pricing (LCP) case. Alternatively, when producers can optimally reset prices every period, the domestic-currency price of good F is $P_{F,t} = \mu_F S_t P_{F,t}^*$ where μ_F is a constant mark-up.

4.2. Trade Openness and Welfare

Conditional on a constant exogenous volatility, we study how optimal exchange rate volatility and the welfare cost $\mathcal{W}_0^{optimal} - \mathcal{W}_0^{peg}$ of a fixed exchange rate are affected by the preference and technology parameters γ_{ch}, γ_{ih}, γ_v, γ_{cn}, γ_{in}, ρ_{cn}, and ρ_{in}. In equilibrium, these parameters map into different degrees of openness and different compositions of imports.[15] We present results for economies where the parameters defining the composition of imports vary across the whole admissible range, and for economies where the import and tradable shares in the consumption and investment aggregates, and the share of intermediates in production, are estimated from input-output data.

[15] The parameters γ_{ch}, γ_{ih}, γ_v are equal in steady state to the shares C_H/C_T, I_H^J/I_T^J, X_H/Y_H. Implicitly, the ratios C_H/C_F and I_H/I_F also depend each exclusively upon γ_{ch}, γ_{ih}. The parameters γ_{cn}, γ_{in} do not uniquely define the steady state tradable shares C_T/C, I_T^J/I^J, since these will depend on the endogenous internal real exchange rates $\frac{P_{T,t}^i}{P_{N,t}}$, $\frac{P_{T,t}^c}{P_{N,t}}$ and on the elasticities ρ_{cn}, ρ_{in}. When parameterizing the model consistently with the input-output table data, we obtain that the value for γ_{nv} is at the upper end of the parameter space. Thus the data prefer a specification where non-traded goods are produced without imported intermediates.

4.2.1. The Ramsey Policy and the Incentive to Deviate from Price Stability

We first examine the behaviour of a parameterized economy under the Ramsey policy. The values for γ_{ch}, γ_{ih}, γ_{v}, γ_{cn}, γ_{in}, ρ_{cn}, and ρ_{in} are set equal to the estimates obtained matching the model's steady state with data obtained from input-output tables for the Czech Republic (see Table 2). Given these estimates, the parameterization of the exogenous stochastic process is chosen to ensure a business cycle behavior consistent with data from emerging market economies, assuming monetary policy follows a Taylor rule with i.i.d. shocks. In the model, business cycle fluctuations are generated by three domestic shocks (total factor productivity in the tradable and non-tradable good sector and shifts in household preferences) and four foreign shocks (price of the domestically-produced tradable good, price of the imported intermediate input, price of the imported tradable good and interest rate on foreign-denominated debt). Appendix C provides details on the parameterization and the business cycle properties of the model.

Table 3 shows the volatility of inflation in the non-tradable sector relative to the volatility of non-tradable output. Under complete markets the policymaker brings about larger deviations from mark-up stability than under incomplete markets. Faia and Monacelli (2008) have shown that, in a small open economy, perfect risk sharing (i.e. complete international financial markets) creates an incentive for the Ramsey policymaker to deviate from price stability. This incentive is due to the fact that, ceteris paribus, by engineering an exchange rate depreciation the Ramsey policymaker can increase domestic consumption relative to foreign.[16] Our result extends their findings by showing that, under incomplete markets, the incentive to deviate from mark-up stability is muted relative to the case of complete markets. Furthermore, our result complements the result discussed by Corsetti et al. (2012) showing that the cooperative policymaker in a two-country model with incomplete markets has an incentive to trade off price stability with the desire to increase risk sharing. Table 3 therefore

[16] De Paoli (2009b) compares different monetary policy rules with the optimal monetary policy under complete and incomplete financial markets in a small open economy, but does not provide a comparison of optimal inflation volatility across alternative financial market assumptions. Pesenti and Tille (2004) discuss the incentive to deviate from prices stability that emerges in a non-cooperative policy game under complete markets are present. In the two-country version of our model with complete financial markets, price stability supports the cooperative allocation.

suggests that in a non-cooperative policy setting, incomplete markets could result in more stable prices than under complete markets.

4.2.2. The Welfare Impact of the Composition of Imports

We present results for the optimal volatility of the nominal exchange rate and the welfare outcome of alternative policy choices in economies where the parameters γ_{ch}, γ_{ih}, γ_v, γ_{cn}, γ_{in}, ρ_{cn}, and ρ_{in} defining the composition of imports vary across the whole admissible range, keeping constant the other parameters of the model

Welfare is measured by the unconditional expectation of the representative household's lifetime utility. As we have log-preferences in consumption, welfare units are equivalent to deterministic steady-state consumption units.

Figure 1 shows welfare isoquants as a function of the share of domestic value added in tradable output γ_v and the bias for non-tradable goods in domestic demand γ_n for four separate values of the home-bias parameter γ_h. For ease of interpretation of the figures, we assume $\gamma_{in} = \gamma_{cn} = \gamma_n$ and $\gamma_{ih} = \gamma_{ch} = \gamma_h$.

Consider the welfare loss as a function of γ_n, for a large value of γ_v, implying a low share of imported inputs. The loss from fixing the exchange rate increases with γ_n. While Figure 1 suggests that the welfare loss from fixing the exchange rate increases the more the economy is closed to trade, this result does not hold unconditionally in our economy. Moving along the horizontal axis, for any given share of non-traded goods, the figure shows that as γ_v decreases, so that tradable goods are produced with a *larger* amount of imported intermediates, the welfare loss *increases*, even if the economy is more open to trade with the rest of the world. This behavior of the welfare function reflects the incentive for the policymaker to move the exchange rate to prevent misalignments in relative prices, highlighted by Mundell (1961) and Friedman (1953). In our model, where international relative prices are exogenous, exchange rate movements can prevent misalignment between tradable and non-tradable prices. The smaller γ_v, and the larger the share of imported intermediates in domestic production, the larger the role played by the exchange rate in preventing inefficient adjustments in the price of non-tradables. This result is consistent with the analytical results discussed in Section 3, and summarized in eq. (23).

Traditional measures of openness that ignore the composition of imports are close to uncorrelated with our welfare measure. Figure 1 showed that being more open through a low γ_{cn} or a low γ_v has opposite effects on the cost of a peg. The relationship between openness, the composition of imports and welfare can be examined directly using the contour plots. The isoquants for our measure of openness - the steady state share of imports to GDP - are overlaid to the welfare isoquants in Figure 1 . This figure is best read by starting from any curve corresponding to a particular degree of openness. Moving along the curve different values for the welfare cost of a peg are found. Along the isoquants representing openness, the same degree of openness is consistent with different compositions of the demand and production input mix. The fact that isoquants of the imports/GDP ratio are not parallel to the ones of the welfare loss implies that the welfare cost of fixing the exchange rate may be vastly different, for a given degree of openness. As a consequence, two countries with the same degree of openness can experience different losses from pegging the exchange rate.[17]

Consider the impact of γ_h, shown across the four different panels. Under incomplete pass-through a change in γ_h changes the share of the tradable good absorption across the F and H good, and thus the share of the sector with inefficient staggered price adjustment for given γ_n. Figure 1 shows that a change in γ_h affects the openness measure, but has a modest effect on the welfare loss for a given level of openness. Eq. (23) provides intuition for this result. As γ_h falls, increasing the overall stickiness of the tradable aggregate, the first two terms of the welfare gap will decrease, while the third term will increase. Thus the overall impact on the welfare cost of fixing the exchange rate depends on the relative size of the variance of the shocks.

Welfare Outcomes in Representative Economies Conditional on Trade Composition Data. In this section we examine the welfare cost of pegging the exchange rate for specific combinations of the parameters $\gamma_{ch}, \gamma_{ih}, \gamma_{cn}, \gamma_{in}, \gamma_v, \rho_{cn}, \rho_{in}$ affecting the demand, import and production

[17] Our estimates of γ_v and γ_{cn} capture very well the degree of openess in the sample. Defining $openness \equiv \frac{export}{GDP} + \frac{Imp.Inv.}{GDP} + \frac{Imp.Cons.}{GDP} + \frac{Imp.Interm.}{GDP}$ and regressing *openness* on γ_{cn} and γ_v we obtain

$$Openness = \underset{[13.5]}{4} \; \underset{[-7.87]}{-3.65}\,\gamma_v \; \underset{[-8.07]}{-2.12}\,\gamma_{cn} : \; R^2 = 0.89,$$

where t-statistics are in square brackets and where we have omitted γ_{in} as its correlation with γ_{cn} is 0.996.

composition of the model, rather than having these parameters vary independently across a given range. We estimate the parameters by minimizing the norm of the distance between eight steady state ratios computed from the OECD input-output tables data and those produced by the model. Table 4 compares the moments in the data and as returned by the estimation for two sample countries, Germany and the Czech Republic. We set the other parameters, including the volatility of exogenous shocks, at the values used in our benchmark parameterization. In the estimation we impose Beta priors on the γ and Gamma priors on the ρ parameters. All priors have very large standard deviations. The use of priors reduces the chance that our numerical algorithm generates large differences in parameter estimates starting from small differences in moment conditions. Figure 2 shows the estimates for the seven parameters, conditional on each set of steady state ratios for the 25 countries in our data set.

This experiment is of interest since variability across parameters combinations does not necessarily translate into variability across welfare outcomes for a given policy. Our representative economies may be different across dimensions that prove to be irrelevant for welfare. Additionally, the analysis in the previous section assumed that all parameter combinations, and the implied import composition, are equally likely, while the estimated parameters may be correlated, so that some parameter combinations are not observed at all in the data.

Given our parameterization, the welfare losses from pegging the exchange rate relative to the Ramsey policy range from about 0.06% to about 0.23% of steady-state consumption (Table 5). Similar values can be found in the literature assessing sub-optimal policies in DSGE models (e.g. Coenen et al., 2009).[18] Figure 3 shows a bubble-plot of the welfare losses in relation to the share of consumption demand for non-tradable goods and the parameter γ_{cn}, the households' bias for non-tradable consumption. The radius of the circles is proportional to the welfare loss. Although for convenience we assign the name of a country as to each combination of parameters, we are examining welfare outcomes for representative economies, rather than for specific countries, since we do not estimate the country-specific volatility of

[18] The losses are sensitive to the definition of the tradability measure used to compute input shares. For example using a country-specific tradability threshold equal to the import share of the wholesale and retail sector, as in Bems (2008), the estimated parameters would generate losses that are about three times as large.

the exogenous shocks driving the business cycle.

The estimates show that very large economies (e.g. Japan, US) - for which the export over GDP ratio is low - are the ones for which the cost of limiting the flexibility in the exchange rate has the highest cost. We do not find, in general, a high correlation between measures of openness and welfare loss, showing that the composition of imports plays an important role. Portugal and Mexico, for example, have similar degree of openness in terms of exports over GDP, yet the cost of pegging the exchange rate is more than twice as large for Mexico than for Portugal. Figure 3 shows instead a large positive correlation between the households' bias for non-tradable consumption γ_{cn} and the cost of pegging the exchange rate. In our model, the tradable share in consumption depends on the steady state value of P_T/P_N and so can differ from γ_{cn}. In our exercise, we find that the correlation of the non-tradable goods share in consumption with γ_{cn} and with the welfare loss is equal respectively to 0.93 and 0.9.[19]

Our theoretical results showed that the correlation between welfare loss and γ_{cn} only holds conditional on the intermediate input share parameter γ_v, while in the representative economies the correlation holds unconditionally. The result obtained for the estimated parameter combinations is the consequence of the correlation across steady state ratios in the input-output tables data. Figure 4 shows pair-wise scatter plots of the share of intermediate goods in GDP, the share of tradable goods in consumption and the share of tradable goods in investment. Countries with a large non-traded share in the consumption basket tend to have a large non-traded share also in the investment basket. In addition, a large non-traded consumption share in the data is highly correlated with a low share of imported intermediates in GDP.

5. Conclusions

We study the relationship between openness, the optimal volatility of the exchange rate and the welfare cost of an exchange rate peg in a model economy where the same degree of openness can be achieved through different compositions of imports across consumption,

[19]The measured correlations between the welfare loss from a peg, the investment non-tradable share and the non-tradable bias in investment γ_{in} are even larger than for the non-tradable bias in consumption γ_{cn}.

investment and intermediate goods. Our results show that the optimal volatility of the exchange rate depends on the composition of imports, and that aggregate measures of the size of trade flows can be close to irrelevant for the ranking of alternative monetary policies.

We derive analytical results using a simple, multi-good SOE model with one period preset prices, where time-varying markups result in inefficiency gaps. The solution to the Ramsey problem shows that the optimal trade-off across inefficiency gaps is independent of the share of imported inputs in production, and thus not directly related to openness. In turn, a larger intermediate imports share is irrelevant for the trade-off, but requires larger optimal movements in the exchange rate to prevent relative price misalignments.

We provide quantitative results using a model extended to include capital and incomplete financial markets, where the parameters governing the composition of international trade are calibrated using OECD input-output data. Inefficiencies in the import sector pricing provide the main incentive for the Ramsey planner to deviate from full stabilization of the non-tradables price, but have a small impact on the welfare cost of a peg. Inefficiencies in the non-tradable sector pricing and the spill-over of shocks across sectors through labor mobility result, under the optimal policy, in substantial volatility of the nominal exchange rate. A peg forces instead the adjustment of relative prices after sectoral shocks on the sticky non-tradable price. This can result in large welfare losses if the share of imported intermediates in the domestic production input mix is high, and at the same time the bias towards non-tradable goods is high.

The relevance of our results is supported by the high variance in the composition of demand and international trade flows that we find in the data. We document from the latest release of the OECD input-output tables that differences in the composition of imports across both industrial and emerging economies are substantial, and provide estimates of the tradable and non-tradable input shares in consumption and investment for 25 countries. Using these data, we parameterize the consumption, investment and production input baskets for 25 representative economies to examine how the variability in parameters implied by the data affects the welfare loss from a peg. Our results show that welfare losses range between 0.06% and 0.23% of steady state consumption. Finally, we find that our estimates of the share of non-tradable goods in consumption and investment are good predictors of the welfare cost from adopting a fixed exchange rate policy, despite the fact that in the model the relationship between non-tradable share and welfare loss holds only conditional on the share of imported intermediates in the domestic production input mix.

Table 1: Non-tradable input shares, demand and import allocation for 25 countries from Input-output tables data.

Country	Imp. inv./gdp	Imp. cons./gdp	Cons./gdp	Inv./gdp	Interm./gdp	N-cons. share	N-inv. share	export/gdp
aut	0.061	0.096	0.507	0.236	0.283	0.237	0.263	0.469
bel	0.062	0.095	0.505	0.204	0.459	0.166	0.208	0.894
can	0.052	0.066	0.518	0.197	0.251	0.31	0.333	0.479
cze	0.083	0.089	0.478	0.274	0.541	0.227	0.288	0.725
deu	0.031	0.056	0.556	0.195	0.197	0.295	0.287	0.391
dnk	0.041	0.066	0.422	0.19	0.127	0.256	0.261	0.487
esp	0.042	0.067	0.569	0.273	0.216	0.378	0.42	0.244
est	0.11	0.122	0.513	0.305	0.588	0.207	0.144	0.807
fin	0.033	0.049	0.442	0.201	0.276	0.513	0.42	0.463
fra	0.026	0.062	0.53	0.197	0.173	0.378	0.406	0.274
gbr	0.035	0.092	0.626	0.169	0.162	0.311	0.393	0.262
grc	0.046	0.103	0.697	0.222	0.184	0.47	0.49	0.179
ita	0.028	0.051	0.571	0.209	0.18	0.449	0.418	0.257
jpn	0.013	0.028	0.567	0.246	0.08	0.687	0.585	0.131
kor	0.056	0.042	0.587	0.314	0.324	0.345	0.269	0.42
mex	0.031	0.035	0.662	0.198	0.196	0.387	0.412	0.252
nld	0.044	0.067	0.47	0.193	0.313	0.241	0.311	0.744
nzl	0.057	0.064	0.563	0.222	0.181	0.329	0.346	0.339
pol	0.068	0.074	0.61	0.221	0.226	0.253	0.24	0.335
prt	0.053	0.107	0.62	0.256	0.244	0.303	0.399	0.26
svk	0.081	0.12	0.529	0.266	0.586	0.183	0.251	0.764
svn	0.09	0.125	0.51	0.266	0.425	0.359	0.362	0.612
swe	0.05	0.056	0.436	0.172	0.278	0.324	0.207	0.492
tur	0.038	0.043	0.716	0.184	0.17	0.217	0.287	0.204
usa	0.015	0.039	0.686	0.197	0.076	0.701	0.577	0.091

Table 2: Benchmark parameter values

Description	symbol	value	Description	symbol	value
Depreciation	δ	0.025	Capital share H	α_H	0.67
Elasticity H-V	ρ_{hv}	0.5	Capital share N	α_N	0.33
Discount factor	β	0.99	Intertemporal elast.	σ	1
Weight on labor	ℓ	24.065	Labor elasticity	η	0.5
Cons. share H-goods	γ_{ch}	0.74	Inv. share H-goods	γ_{ih}	0.65
Inv. bias N-goods	γ_{in}	0.2	Cons. bias N-goods	γ_{cn}	0.13
Elasticity bond premium	–	0.01	Share value added H	γ_v	0.54
Share of gov. spending N	–	0.4	Elasticity of demand	θ	-11
Calvo probability H	ϑ	0.8	Calvo probability F	ϑ_F	0.8
Cons. dem. elasticity H	ρ_{ch}	2	Inv. dem. elasticity H	ρ_{ih}	2
Cons. dem. elasticity N	ρ_{cn}	0.7	Inv. dem. elasticity N	ρ_{in}	0.75
Elasticity Invest. adj. cost	–	0.5			
Shocks					
Autocorrelation a^H	ρ_{a^H}	0.95	Autocorrelation a^N	ρ_{a^N}	0.95
Autocorrelation d	ρ_d	0.85	Autocorrelation policy shock	ρ_i	0
Autocorrelation p^*_H	ρ_{pH}	0.75	Autocorrelation p^*_F	ρ_{pF}	0.71
Autocorrelation i^*	ρ_{i^*}	0.95	Autocorrelation p^*_M	ρ_{PM}	0.85
Std. dev. a^H	σ_{a^H}	0.533%	Std. dev. a^N	σ_{a^N}	0.533%
Std. dev. p^*_H	σ_{pH}	0.735%	Std. dev. d	σ_d	0.9%
Std. dev. i^*	σ_{i^*}	0.05%	Std. dev. policy shock	σ_i	0.05%
Std. dev. p^*_M	σ_{pM}	1.39%	Std. dev. p^*_F	σ_{pF}	2.12%
Policy					
Policy smoothing	χ	0.8	Policy resp. output	ω_y	0.4
Policy resp. exchange rat.	ω_E	0.1	Policy resp. infl.	ω_π	2

671

Table 3: Volatility of non-tradable sector inflation relative to non-tradable output (in percent) under optimal policy.†

Case	Shock						
	$A_{H,t}$	$A_{N,t}$	D_t	$P^*_{H,t}$	i^*_t	$P^*_{F,t}$	$P^*_{M,t}$
Complete Markets	12.12	13.93	18.60	41.67	0.00	26.42	30.24
Incomplete Markets	11.27	5.88	2.39	18.59	5.57	19.78	17.86

† Note: Each column reports the ratio of the standard deviation of $\pi_{N,t}$ to the standard deviation of Y_N (in log-deviations), in an economy where cyclical volatility is generated by the single exogenous shock.

Table 4: Moments for Germany and the Czech Republic used in estimation of trade parameters. Input-output tables data and values returned by the estimation.

	Deu		Cze	
Ratio	Model	Data	Model	Data
Imported inv./ gdp	0.034	0.031	0.083	0.083
Imported cons./ gdp	0.061	0.056	0.089	0.089
Cons./gdp	0.47	0.556	0.489	0.478
Inv./gdp	0.313	0.195	0.314	0.274
export over gdp	0.299	0.391	0.711	0.725
Intermediates/gdp	0.204	0.197	0.539	0.541
Non-tradable consumption share	0.293	0.295	0.221	0.227
Non-tradable investment share	0.385	0.287	0.308	0.288

Table 5: Estimated non-tradable bias for consumption and investment goods, and loss from pegging the exchange rate in percent of steady state consumption.

Country	γ_{cn}	γ_{in}	Loss
1) bel	0.104	0.144	0.09 [0.097 (1)]
3) est	0.089	0.117	0.093 [0.133 (13)]
2) pol	0.154	0.184	0.093 [0.099 (2)]
4) aut	0.147	0.188	0.097 [0.1 (4)]
5) dnk	0.188	0.218	0.099 [0.1 (3)]
6) tur	0.183	0.216	0.103 [0.105 (5)]
7) svk	0.105	0.165	0.111 [0.121 (8)]
8) swe	0.187	0.208	0.113 [0.117 (6)]
9) deu	0.213	0.242	0.12 [0.12 (7)]
10) kor	0.19	0.213	0.123 [0.127 (10)]
11) nld	0.188	0.229	0.124 [0.124 (9)]
12) nzl	0.232	0.267	0.125 [0.127 (12)]
13) cze	0.126	0.2	0.129 [0.138 (16)]
14) prt	0.23	0.265	0.13 [0.127 (11)]
15) can	0.23	0.265	0.135 [0.136 (15)]
16) gbr	0.286	0.321	0.142 [0.136 (14)]
17) esp	0.272	0.302	0.152 [0.153 (17)]
18) fra	0.307	0.341	0.162 [0.16 (18)]
19) svn	0.221	0.273	0.168 [0.178 (19)]
20) mex	0.325	0.352	0.179 [0.18 (20)]
21) grc	0.363	0.386	0.183 [0.182 (21)]
22) ita	0.344	0.371	0.184 [0.185 (22)]
23) fin	0.375	0.401	0.242 [0.243 (23)]
24) jpn	0.56	0.568	0.259 [0.261 (24)]
25) usa	0.617	0.63	0.283 [0.285 (25)]

Note: In brackets we report the value obtained by adding to the
loss the value (in deviation from the steady-state) of the initial-
673 period constraint imposed on the optimal timeless policy (see
Benigno and Woodford, 2006), as well as the implied ranking.

Figure 1: Openness and welfare, contour plots for selected trade parameters (assuming $\gamma_{cn} = \gamma_{in} = \gamma_N$ and $\gamma_{ch} = \gamma_{ih} = \gamma_H$). Welfare measured as loss from a pegged exchange rate relative to optimal policy, in percent of steady-state consumption units.

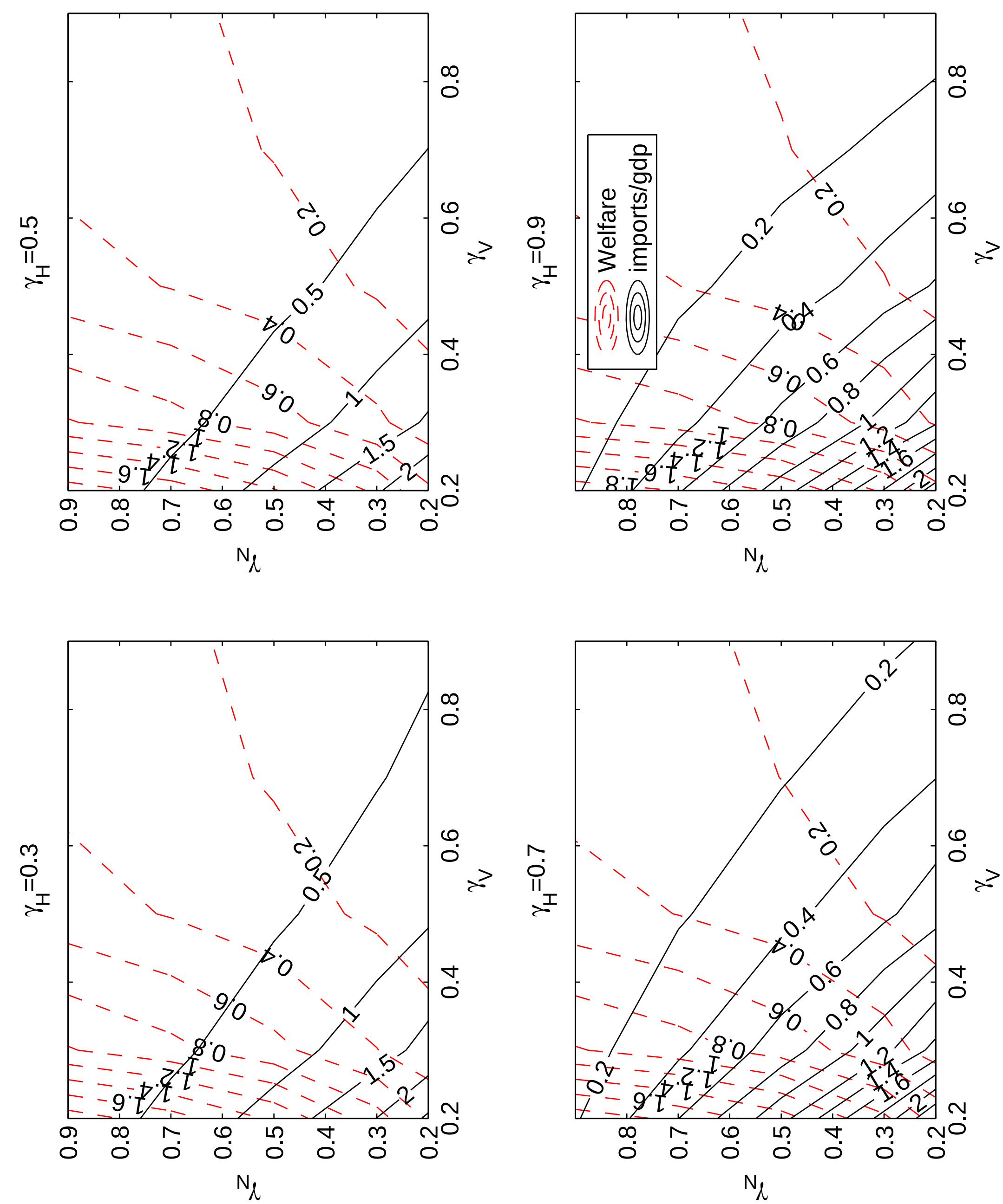


Figure 2: Estimated bias and elasticity parameters from Input-output tables for 25 countries.

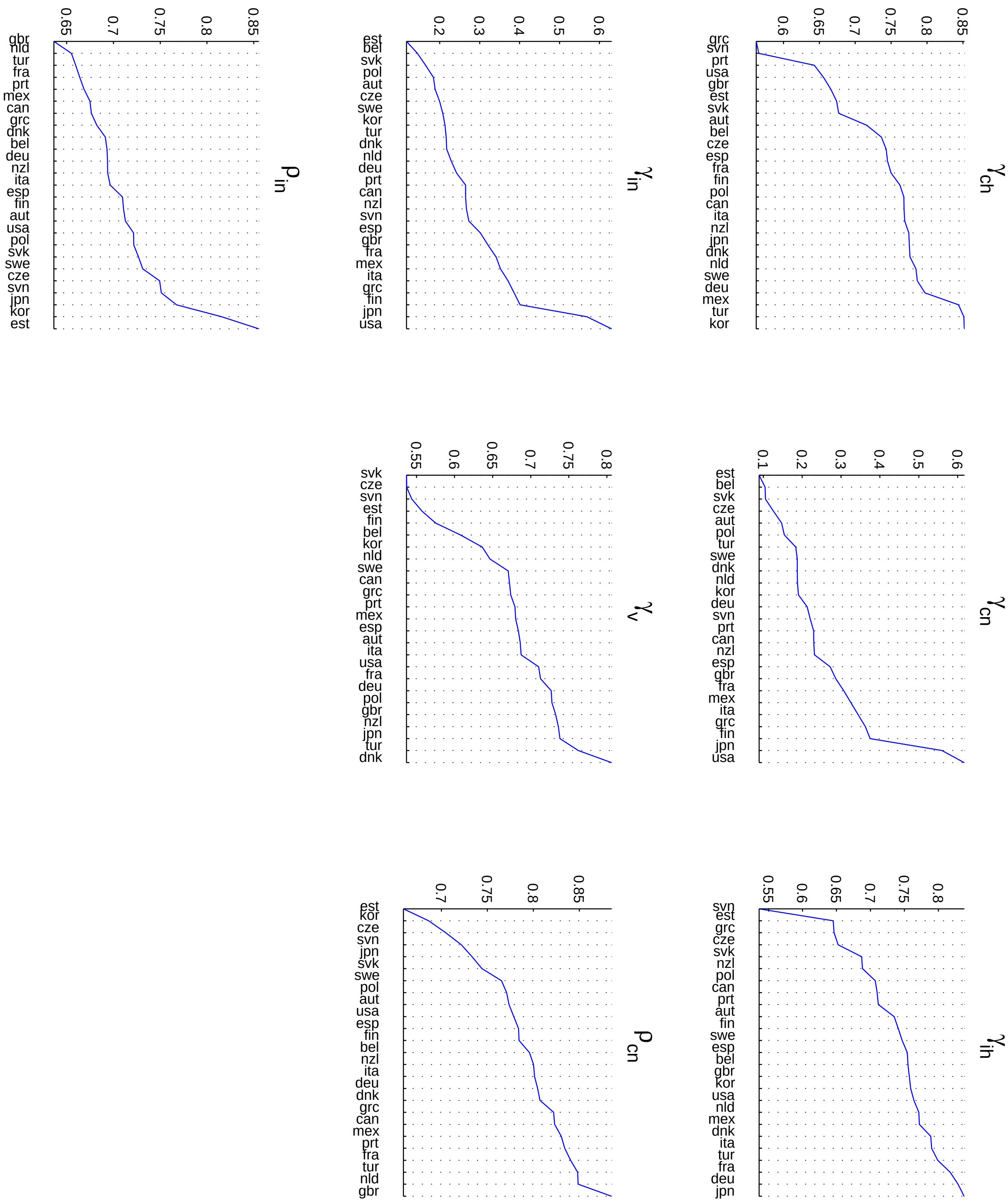


Figure 3: Welfare loss from exchange rate peg vs. non-tradable share in consumption and non-tradable consumption bias γ_{cn} for 25 representative economies with trade parameter combinations estimated from Input-output tables. Loss is proportional to the radius of circles'.

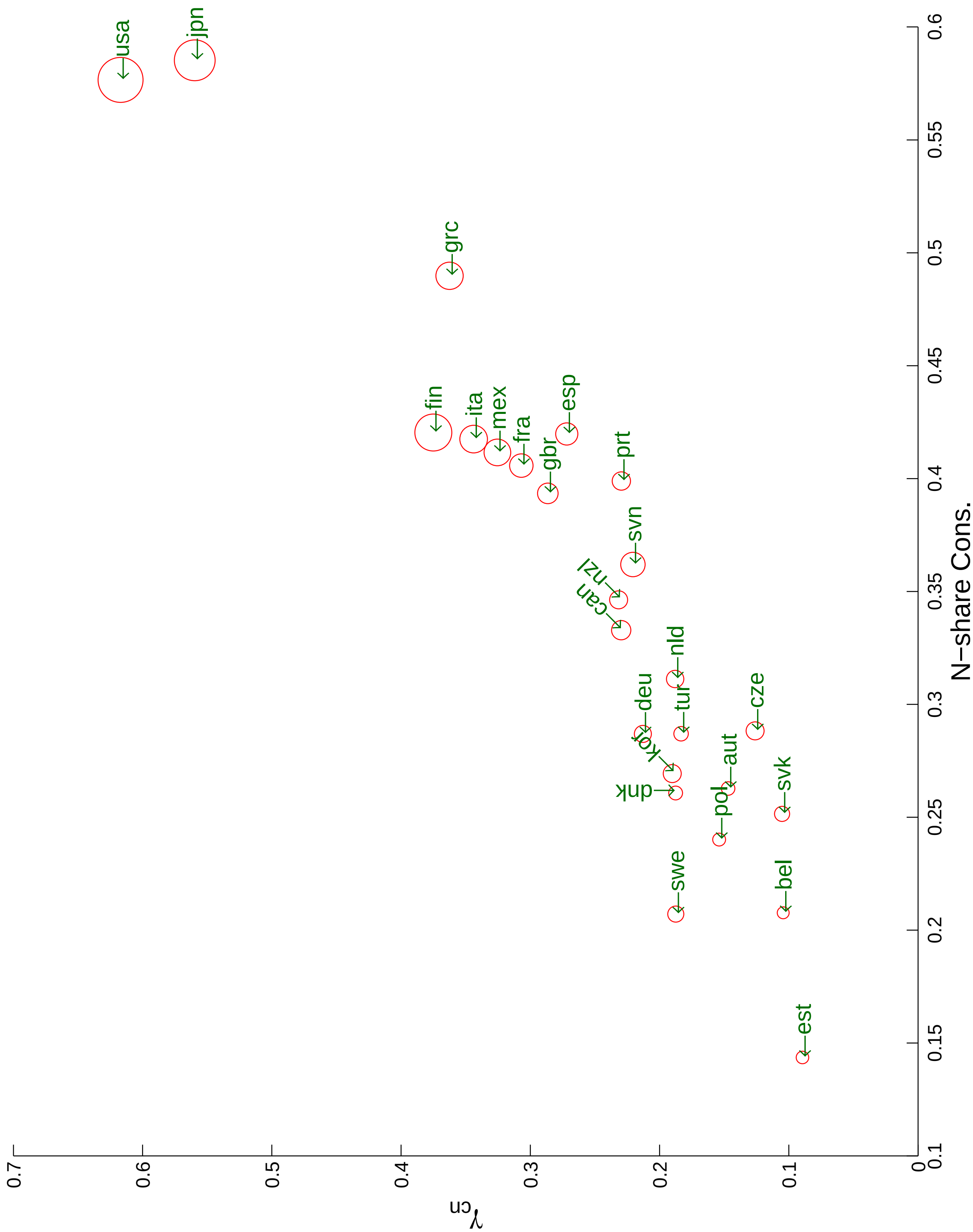
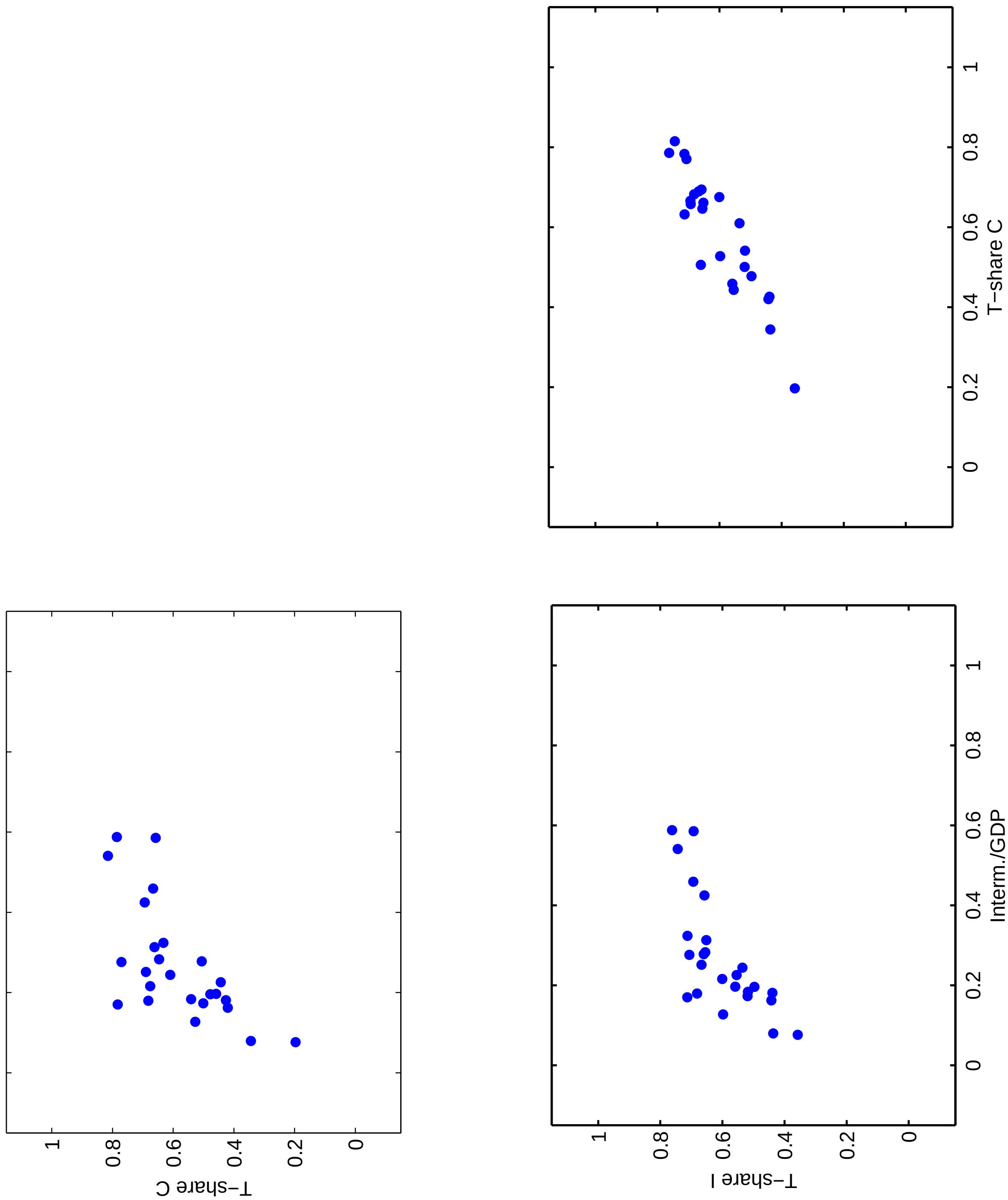


Figure 4: Correlation between tradable share in final demand and intermediate imports for 25 representative economies with trade parameter combinations derived from Input-output tables.



Appendix

Appendix A. SOE with intermediate inputs, LCP and one-period preset prices: Derivation of the Ramsey policy

Summary of equations

Define

$$\begin{aligned}\mu_t &= P_t C_t \\ \mu_t^* &= P_t^* C_t^* \\ \Psi_{N,t} &= \frac{U_{c,t}}{P_t} Y_{N,t} \\ \Psi_{F,t} &= \frac{U_{c,t}}{P_t}\frac{P_{F,t}C_{F,t}}{P_{s,F,t}}.\end{aligned}$$

where $U_{c,t}$ is the marginal utility of consumption. Let the pre-tax steady-state markups in the monopolistically competitive domestic and foreign sectors be equal to $\mu_N = \mu_F = \frac{\varrho}{\varrho-1}$. The constraints of the policymaker can be summarized by the system of equations:

$$P_{T,t} = \gamma_H^{-\gamma_H} \left(1-\gamma_H\right)^{-(1-\gamma_H)} \left(S_t P_{H,t}^*\right)^{\gamma_H} P_{F,t}^{1-\gamma_H} \tag{A.1}$$

$$\frac{\mu_t}{\kappa \mu_t^*} = S_t \tag{A.2}$$

$$\frac{\mu_N}{\gamma_N}\frac{C_{N,t}}{P_t C_t} = \left(\frac{E_{t-1}\Psi_{N,t} Z_{N,t}^{-1} W_t}{E_{t-1}\Psi_{N,t}}\right)^{-1} \tag{A.3}$$

$$C_{H,t} = \left(1-\gamma_N\right)\gamma_H \left(\frac{S_t P_{H,t}^*}{P_{T,t}}\right)^{-1} \left(\frac{P_{T,t}}{P_t}\right)^{-1} C_t \tag{A.4}$$

$$C_{F,t} = \left(1-\gamma_N\right)\left(1-\gamma_H\right) \left(\frac{P_{F,t}}{P_{T,t}}\right)^{-1} \left(\frac{P_{T,t}}{P_t}\right)^{-1} C_t \tag{A.5}$$

$$W_t = H_t^{\eta} P_t C_t \tag{A.6}$$

$$P_{N,t} = \mu_N \frac{E_t \Psi_{N,t+1} Z_{N,t+1}^{-1} W_{t+1}}{E_t \Psi_{N,t+1}} \tag{A.7}$$

$$\gamma_F^{\gamma_F}\left(1-\gamma_F\right)^{(1-\gamma_F)} P_{F,t}\left(S_t P_{F,t}^*\right)^{(\gamma_F-1)} = p_{F,t}^{\gamma_F} = \left(\mu_F \frac{E_{t-1}\Psi_{F,t} S_t P_{F,t}^*}{E_{t-1}\Psi_{F,t}}\right)^{\gamma_F}, \tag{A.8}$$

$$S_t P_{H,t}^* = Z_{H,t}^{-1}(1-\gamma_v)^{-(1-\gamma_v)}\left(\gamma_v\right)^{((1-\gamma_v)-1)}\left(H_t^{\eta} P_t C_t\right)^{(\gamma_v)}\left(S_t P_{M,t}^*\right)^{(1-\gamma_v)} \tag{A.9}$$

$$H_t = \left(\gamma_v\right) S_t P_{H,t}^* \frac{Y_{H,t}}{H_t^{\eta} P_t C_t} + Z_{N,t}^{-1} C_{N,t} \tag{A.10}$$

$$M_t = (1-\gamma_v) P^*_{H,t} \frac{Y_{H,t}}{P^*_{M,t}} \tag{A.11}$$

$$Y_{H,t} = C_{H,t} + C^*_{H,t} \tag{A.12}$$

$$P_t = \gamma_n^{-\gamma_n} \left(1-\gamma_n\right)^{-(1-\gamma_n)} P^{\gamma_n}_{N,t-1} P^{1-\gamma_n}_{T,t} \tag{A.13}$$

where eq. (A.8) is obtained using the fact that $P_{s,F,t} = p_{F,t-1}$ and $Y_{s,F,t} = \gamma_F \left(\frac{P_{s,F,t}}{P_{F,t}}\right)^{-1} C_{F,t}$, thus the optimal sticky-price chosen by foreign good importers can be written as $p_{F,t} = \mu_F \frac{E_{t-1}\Psi_{F,t} S_t P^*_{F,t}}{E_{t-1}\Psi_{F,t}}$. Eqs. (A.10) and (A.11) give the conditional factor demands in the tradable sector. The variable $C^*_{H,t}$ is net exports of the tradable good H.

Reduction of the non-linear model

Combining the equilibrium conditions, eq. (A.9) can berewritten as

$$\frac{\mu_t}{\kappa\mu^*_t} P^*_{H,t} = Z^{-1}_{H,t} (1-\gamma_v)^{-(1-\gamma_v)} \left(\gamma_v\right)^{((1-\gamma_v)-1)} \left(H^\eta_t \mu_t\right)^{(1-(1-\gamma_v))} \left(\frac{\mu_t}{\kappa\mu^*_t} P^*_{M,t}\right)^{(1-\gamma_v)} \tag{A.14}$$

Simplifying the μ_t terms, obtain

$$\frac{1}{\kappa\mu^*_t} P^*_{H,t} = Z^{-1}_{H,t} (1-\gamma_v)^{-(1-\gamma_v)} \left(\gamma_v\right)^{((1-\gamma_v)-1)} \left(H^\eta_t\right)^{(1-(1-\gamma_v))} \left(\frac{1}{\kappa\mu^*_t} P^*_{M,t}\right)^{(1-\gamma_v)}. \tag{A.15}$$

Eq. (A.15) shows that total labor hours H_t do not depend on policy. This is the consequence of assuming log-utility, Cobb-Douglas aggregators in consumption and production, complete markets and perfect competition in the tradable sector against foreign producers of the good H.

Using the result from the FOC of the household that

$$\Psi_{N,t} = \frac{C_{N,t}}{P_t C_t} = \frac{\gamma_N}{P_{N,t}} \tag{A.16}$$

$$\Psi_{F,t} = \gamma_F \frac{P_{F,t} C_{F,t}}{P_t C_t} \frac{1}{P_{s,F,t}} = \gamma_F (1-\gamma_N)(1-\gamma_h) \frac{1}{P_{s,F,t}} \tag{A.17}$$

and the fact that $P_{s,F,t} = p_{F,t-1}$, $P_{N,t} = p_{N,t-1}$ we obtain that the $\Psi_{N,t+1}$ terms in the non-tradable sector pricing equation are known at time t, and they cancel out. Similarly, the $\Psi_{F,t}$ terms in the import sector pricing equation cancel out. The equilibrium can be described by the four equations:

$$\mu_N E_{t-1} Z_{N,t}^{-1} H_t^{\eta} \mu_t = \left[\frac{1}{\gamma_N} \frac{C_{N,t}}{\mu_t} \right]^{-1} \tag{A.18}$$

$$\gamma_F^{\gamma_F} \left(1-\gamma_F\right)^{(1-\gamma_F)} P_{F,t} \left(\frac{\mu_t}{\kappa \mu_t^*} P_{F,t}^* \right)^{(\gamma_F - 1)} = \left(\mu_F E_{t-1} \frac{\mu_t}{\kappa \mu_t^*} P_{F,t}^* \right)^{\gamma_F} \tag{A.19}$$

$$\frac{1}{\kappa \mu_t^*} P_{H,t}^* = Z_{H,t}^{-1} (1-\gamma_v)^{-(1-\gamma_v)} \left(\gamma_v\right)^{((1-\gamma_v)-1)} \left(H_t^{\eta}\right)^{(\gamma_v)} \left(\frac{1}{\kappa \mu_t^*} P_{M,t}^* \right)^{(1-\gamma_v)} \tag{A.20}$$

$$P_t = \gamma_n^{-\gamma_n} \left(1-\gamma_n\right)^{-(1-\gamma_n)} \left(E_{t-1} Z_{N,t}^{-1} H_t^{\eta} \mu_t\right)^{\gamma_n} \left(\gamma_H^{-\gamma_H} \left(1-\gamma_H\right)^{-(1-\gamma_H)} \left(\frac{\mu_t}{\kappa \mu_t^*} P_{H,t}^* \right)^{\gamma_H} P_{F,t}^{1-\gamma_H} \right)^{1-\gamma_n} \tag{A.21}$$

Equation (A.18) defines the relationship between the optimal predetermined price $p_{N,t-1} = \mu_N E_{t-1} Z_{N,t}^{-1} H_t^{\eta} \mu_t$ in the N sector and demand for the N good. Equation (A.19) defines a relationship between nominal income ($\mu_t \equiv P_t C_t$) and the price of imported foreign goods ($P_{F,t}$), using the optimal predetermined price $p_{F,t-1} = \mu_F E_{t-1} \frac{\mu_t}{\kappa \mu_t^*} P_{F,t}^*$ among the sticky-price importers . Equation (A.21) defines a relationship between the price level (P_t) and nominal income.

Ramsey problem

Following Corsetti and Pesenti (2001) and Corsetti (2006) we can assume policy sets μ_t, or, through the financial asset equilibrium condition, the nominal exchange rate S_t.

To specify the Ramsey problem as in the main text, we use the result that in equilibrium H_t is independent of policy. Therefore, the constraints for the Ramsey problem can be summarized using only the CPI aggregator and the pricing optimality conditions from the competitive equilibrium, which can be written in terms of μ_t, S_t, H_t and exogenous shocks. The financial asset equilibrium condition implies $S_t = \frac{\mu_t}{\kappa \mu_t^*}$. Therefore, similarly to Woodford (2003, p. 570) and Adão et al. (2003), we can rewrite P_t, $P_{F,t}$ as

$$\begin{aligned} P_t &= \kappa_N \left(E_{t-1} Z_{N,t}^{-1} H_t^{\eta} \mu_t\right)^{\gamma_n} \times \\ & \left(\kappa_H \left(\frac{\mu_t}{\kappa \mu_t^*} P_{H,t}^* \right)^{\gamma_H} P_{F,t}^{1-\gamma_H} \right)^{1-\gamma_n} \end{aligned} \tag{A.22}$$

and

$$P_{F,t} = \kappa_F \left(\frac{\mu_t}{\kappa \mu_t^*} P_{F,t}^* \right)^{(1-\gamma_F)} \left(E_{t-1} \frac{\mu_t}{\kappa \mu_t^*} P_{F,t}^* \right)^{\gamma_F}$$

where $\kappa_N = \gamma_n^{-\gamma_n} \left(1-\gamma_n\right)^{-(1-\gamma_n)}$, $\kappa_H = \gamma_H^{-\gamma_H} \left(1-\gamma_H\right)^{-(1-\gamma_H)}$, and $\kappa_F = \mu_F \gamma_F^{-\gamma_F} \left(1-\gamma_F\right)^{-(1-\gamma_F)}$.

Now define

$$\begin{aligned}\Omega_{P,t} &\equiv P_t\left(\frac{\mu_t}{\kappa\mu_t^*}P_{H,t}^*\right)^{(\gamma_n-1)\gamma_H}\left(\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*\right)^{(\gamma_F-1)(1-\gamma_H)(1-\gamma_n)}\\ &= \kappa_N\left(E_{t-1}Z_{N,t}^{-1}H_t^\eta\mu_t\right)^{\gamma_n}\left(\kappa_H\left(\kappa_F\left(E_{t-1}\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*\right)^{\gamma_F}\right)^{1-\gamma_H}\right)^{1-\gamma_n}\end{aligned}$$

so that $\Omega_{P,t}$ is predetermined at time t.

After defining

$$\Theta_t \equiv \left(\kappa_H\left(\kappa_F\left(E_{t-1}\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*\right)^{\gamma_F}\right)^{1-\gamma_H}\right)^{1-\gamma_n}$$

which is predetermined at time t, the policymaker objective function can be rewritten as

$$E_0\sum_{t=0}^{\infty}\beta^t\left[\log(\mu_t)-\log(\Omega_{P,t})+\log(\mu_t)\left((\gamma_n-1)\gamma_H+(\gamma_F-1)(1-\gamma_H)(1-\gamma_n)\right)+t.i.p.\right]$$

where the term independent of policy also includes a term equal to

$$\log\left(\left(\frac{1}{\kappa\mu_t^*}P_{H,t}^*\right)^{(\gamma_n-1)\gamma_H}\left(\frac{1}{\kappa\mu_t^*}P_{F,t}^*\right)^{(\gamma_F-1)(1-\gamma_H)(1-\gamma_n)}\right).$$

Appropriately rewriting the constraints in terms of the variables $\Omega_{P,t},\Theta_t$, we obtain the Lagrangian for the Ramsey problem:

$$\begin{aligned}&\max_{\mu_t,\Omega_t,\Theta_t} E_0\sum_{i=0}^{\infty}\beta^i\left[(1+(\gamma_n-1)\gamma_H+(\gamma_F-1)(1-\gamma_H)(1-\gamma_n))\log(\mu_{t+j})-\log(\Omega_{P,t+j})\text{-t.i.p.}+\right.\\ &+E_{-1}\lambda_{t-1}\left[\left(\frac{\Omega_{P,t+j}}{\kappa_N\Theta_{t+j}}\right)^{\frac{1}{\gamma_n}}-Z_{N,t+j}^{-1}H_{t+j}^\eta\mu_{t+j}\right]\\ &\left.+\,E_{-1}\varphi_{t-1}\left[\left(\frac{\Theta_{t+j}}{\kappa_H^{(1-\gamma_n)}\kappa_F^{(1-\gamma_H)(1-\gamma_n)}}\right)^{\frac{1}{\gamma_F(1-\gamma_H)(1-\gamma_n)}}-\frac{\mu_{t+j}}{\kappa\mu_{t+j}^*}P_{F,t+j}^*\right]\right]\end{aligned}$$

where λ_t and φ_t are Lagrange multipliers. The FOCs for teh problem are:

$$\Omega_{P,t}:\ -\Omega_{P,t}^{-1}+\frac{1}{\gamma_n}\lambda_{t-1}\left(\kappa_N\Theta_t\right)^{-\frac{1}{\gamma_n}}\Omega_{P,t}^{\frac{1}{\gamma_n}-1}=0$$

$$\Theta_t \quad : \quad 0 = -\lambda_{t-1}\frac{1}{\gamma_n}\left(\frac{\Omega_{P,t}}{\kappa_N}\right)^{\frac{1}{\gamma_n}}\Theta_t^{\frac{1}{\gamma_n}-1} \tag{A.23}$$

$$+\varphi_{t-1}\frac{1}{\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)} \tag{A.24}$$

$$\left(\frac{1}{\kappa_H^{(1-\gamma_n)}\kappa_F^{(1-\gamma_H)(1-\gamma_n)}}\right)^{\frac{1}{\gamma_F(1-\gamma_H)(1-\gamma_n)}}\Theta_t^{\frac{1}{\gamma_F(1-\gamma_H)(1-\gamma_n)}-1} \tag{A.25}$$

$$\mu_t : \left(1+\left(\gamma_n-1\right)\gamma_H+\left(\gamma_F-1\right)\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)\mu_t^{-1}-\lambda_{t-1}Z_{N,t}^{-1}H_t^{\eta}-\varphi_{t-1}\frac{1}{\kappa\mu_{t+j}^*}P_{F,t+j}^*=0$$

Rearranging we get

$$\lambda_{t-1}=\gamma_n\left(\kappa_N\Theta_t\right)^{\frac{1}{\gamma_n}}\Omega_{P,t}^{-\frac{1}{\gamma_n}}$$

which we replace in the second FOC to obtain

$$\varphi_{t-1}=\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\left(\kappa_H^{(1-\gamma_n)}\kappa_F^{(1-\gamma_H)(1-\gamma_n)}\right)^{\frac{1}{\gamma_F(1-\gamma_H)(1-\gamma_n)}}\Theta_t^{\frac{1}{\gamma_F(1-\gamma_H)(\gamma_n-1)}}=0$$

Replacing $\varphi_{t-1}$and λ_{t-1} in the FOC for μ_t gives

$$\begin{aligned} 0 \;=\; & \left(1+\left(\gamma_n-1\right)\gamma_H+\left(\gamma_F-1\right)\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)\mu_t^{-1}+ \\ & -\gamma_n\kappa_N^{\frac{1}{\gamma_n}}\Theta_t^{\frac{1}{\gamma_n}}\Omega_{P,t}^{-\frac{1}{\gamma_n}}Z_{N,t}^{-1}H_t^{\eta}+ \\ & -\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\left(\kappa_H^{(1-\gamma_n)}\kappa_F^{(1-\gamma_H)(1-\gamma_n)}\right)^{\frac{1}{\gamma_F(1-\gamma_H)(1-\gamma_n)}}\Theta_t^{\frac{1}{\gamma_F(1-\gamma_H)(\gamma_n-1)}}\frac{1}{\kappa\mu_{t+j}^*}P_{F,t+j}^* \end{aligned} \tag{A.26}$$

Recall that

$$\Theta_t=\kappa_H^{(1-\gamma_n)}\kappa_F^{(1-\gamma_H)(1-\gamma_n)}\left(E_{t-1}\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*\right)^{\gamma_F(1-\gamma_H)(1-\gamma_n)}$$

and

$$\Omega_{P,t}=\kappa_N\left(E_{t-1}Z_{N,t}^{-1}H_t^{\eta}\mu_t\right)^{\gamma_n}\kappa_H^{(1-\gamma_n)}\kappa_F^{(1-\gamma_H)(1-\gamma_n)}\left(E_{t-1}\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*\right)^{\gamma_F(1-\gamma_H)(1-\gamma_n)}$$

Replacing these into equation (A.26) obtain:

$$\begin{aligned}0 &= \left(1+\left(\gamma_n-1\right)\gamma_H+\left(\gamma_F-1\right)\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)+\\ &-\gamma_n\frac{Z_{N,t}^{-1}H_t^{\eta}\mu_t}{E_{t-1}\left(Z_t^{-1}H_t^{\eta}\mu_t\right)}+\\ &-\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\frac{\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*}{E_{t-1}\left(\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*\right)}\end{aligned} \tag{A.27}$$

Note that

$$\frac{Z_{N,t}^{-1}H_t^{\eta}\mu_t}{E_{t-1}\left(Z_t^{-1}H_t^{\eta}\mu_t\right)}\equiv\frac{MC_{N,t}}{P_{N,t}}\equiv\xi_{N,t}$$

and

$$\frac{\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*}{E_{t-1}\left(\frac{\mu_t}{\kappa\mu_t^*}P_{F,t}^*\right)}=\frac{MC_{F,t}}{p_{f,t}}\equiv\xi_{F,t}$$

where $\xi_{N,t}$ and $\xi_{F,t}$ are the inverse stochastic mark-ups. Note that we assume firms are subsidized through lump-sum taxes levied on households, so that the flexible-price mark-up is equal to $\mu_i(1-\tau_{\mu_i})=1\ for\ i=\{N,F\}$. In the absence of the subsidy, $\xi_{i,t}=\frac{MC_{i,t}^{nom}}{P_{i,t}}\mu_i$.

The first best would be achieved by setting $\xi_{N,t}=\xi_{F,t}=1$.[20] Eq. (A.27) shows that complete markup (price) stabilization in either of the two sectors is not optimal. Similarly, complete stabilization of the exchange rate S_t is optimal only under very specific assumptions. For example, with nominal exchange rate stability and constant import prices of F goods we have

$$\left(1+\left(\gamma_n-1\right)\gamma_H-1\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)=\gamma_n\frac{Z_{N,t}^{-1}H_t^{\eta}\mu_t^*}{E_{t-1}\left(Z_t^{-1}H_t^{\eta}\mu_t^*\right)}$$

which is satisfied only for $\gamma_n=0$, or if non-traded goods prices are flexible (as in Duarte and Obstfeld, 2008).

[20]Note that in the steady state we have

$$\left(1+\left(\gamma_n-1\right)\gamma_H+\left(\gamma_F-1\right)\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)-\gamma_n-\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right) = 0$$

Second order approximation

The FOC (A.27) can be written as the sum of two terms, each involving the nominal exchange rate S_t.The first term depends on $H_t^{\eta}\mu_t$, which in turn using equation (A.20) can be rewritten as a function of exogenous variables and the term $\frac{\mu_t}{\kappa\mu_t^*} = S_t$. The second term depends explicitely on $\frac{\mu_t}{\kappa\mu_t^*} = S_t$. Thus the FOC for the Ramsey problem implicitely defines an optimal targeting rule for the nominal exchange rate S_t of the form

$$1 = \Gamma \frac{S_t X_t}{E_{t-1} S_t X_t} + (1-\Gamma) \frac{S_t Y_t}{E_{t-1} S_t Y_t}$$

Define the log-difference of the variable X_t as $\widetilde{X}_t = \log(X_t) - \log(X_{SS})$ where X_{SS} is the steady state value of X_t.Then, following Lombardo and Sutherland (2007), a second order approximation gives

$$\begin{aligned} \Gamma\left[\tilde{S}_t^{II} + \tilde{X}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{X}_t^I\right)^2 - E_{t-1}\left(\tilde{S}_t^{II} + \tilde{X}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{X}_t^I\right)^2\right)\right] & + \\ (1-\Gamma)\left[\tilde{S}_t^{II} + \tilde{Y}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{Y}_t^I\right)^2 - E_{t-1}\left(\tilde{S}_t^{II} + \tilde{Y}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{Y}_t^I\right)^2\right)\right] & = 0 \end{aligned}$$

The first order approximation yields an explicit function for S_t

$$\tilde{S}_t^I = -\Gamma \tilde{X}_t^I - (1-\Gamma)\tilde{Y}_t^I + \Gamma E_{t-1}\tilde{X}_t^I + (1-\Gamma) E_{t-1}\tilde{Y}_t^I$$

This approximation shows that the nominal exchange rate S_t follows an iid process. By the same logic, S_t must be iid at any order of approximation. Then, the second order solution must be

$$\begin{aligned} \tilde{S}_t^{II} &= -\Gamma\left[\tilde{X}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{X}_t^I\right)^2 - E_{t-1}\left(\tilde{X}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{X}_t^I\right)^2\right)\right] + \\ &- (1-\Gamma)\left[\tilde{Y}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{Y}_t^I\right)^2 - E_{t-1}\left(\tilde{Y}_t^{II} + \frac{1}{2}\left(\tilde{S}_t^I + \tilde{Y}_t^I\right)^2\right)\right] \end{aligned}$$

Rewriting eq. (A.27) as

$$1 = (1-\Gamma)\frac{Z_{N,t}^{-1}\left(P_{H,t}^* Z_{H,t}\left(P_{M,t}^*\right)^{-(1-\gamma_v)}\right)^{\frac{1}{(\gamma_v)}} S_t}{E_{t-1}\left(Z_{N,t}^{-1}\left(Z_{H,t}\left(P_{M,t}^*\right)^{-(1-\gamma_v)}\right)^{\frac{1}{(\gamma_v)}} S_t\right)} + \quad \Gamma\frac{S_t P_{F,t}^*}{E_{t-1}\left(S_t P_{F,t}^*\right)}$$

define

$$X_t = Z_{N,t}^{-1}\left(P_{H,t}^{*} Z_{H,t}\left(P_{M,t}^{*}\right)^{-(1-\gamma_v)}\right)^{\frac{1}{(\gamma_v)}}$$

$$Y_t = P_{F,t}^{*}$$

$$\Gamma = \frac{\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)}{\left(\gamma_n+\gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)}$$

Using the first order expansion of X_t :

$$\tilde{X}_t = -\tilde{Z}_{N,t} + \frac{1}{\gamma_v}\left(\tilde{P}_{H,t}^{*} + \tilde{Z}_{H,t} - (1-\gamma_v)\tilde{P}_{M,t}^{*}\right)$$

obtain using the results for $\tilde{S}_t^I,\ \tilde{S}_t^{II}$ that the first order solution for S_t is

$$\tilde{S}_t^I = -\left(1-\Gamma\right)\left(-\varepsilon_{N,t} + \frac{1}{\gamma_v}\left(\varepsilon_{H,t}^{*} + \varepsilon_{H,t} - (1-\gamma_v)\varepsilon_{M,t}^{*}\right)\right) - \Gamma\varepsilon_{F,t}^{*}$$

and the second order solution is

$$\begin{aligned}\tilde{S}_t^{II} &= -\left(1-\Gamma\right)\left(-\varepsilon_{N,t} + \frac{1}{\gamma_v}\left(\varepsilon_{H,t}^{*} + \varepsilon_{H,t} - (1-\gamma_v)\varepsilon_{M,t}^{*}\right)\right) - \Gamma\varepsilon_{F,t}^{*} \\ &\quad -\frac{\left(1-\Gamma\right)\Gamma}{2}\left[\tilde{X}_t^2 + \tilde{Y}_t^2 - 2\tilde{X}_t\tilde{Y}_t - E_{t-1}\left(\tilde{X}_t^2 + \tilde{Y}_t^2 - 2\tilde{X}_t\tilde{Y}_t\right)\right]\end{aligned}$$

To obtain the welfare loss from pegging the exchange rate relative to the optimal policy, we evaluate the welfare under the two policies using a second-order approximation of the constraint $\Omega_{P,t}$. Recall that welfare is given by

$$E_0\sum_{t=0}^{\infty}\beta^t\left[\left(1+\left(\gamma_n-1\right)\gamma_H+\left(\gamma_F-1\right)\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)\log\left(\mu_t\right)-\log\left(\Omega_{P,t}\right)+t.i.p. \quad \text{(A.28)}\right.$$

Taking a second order approximation of the equation defining $\Omega_{P,t}$ obtain:

$$\begin{aligned}\tilde{\Omega}_{P,t} + \frac{1}{2}\tilde{\Omega}_{P,t}^2 &= E_{t-1}\gamma_n\left[-\tilde{Z}_{N,t} + \eta\tilde{H}_t + \tilde{\mu}_t + \frac{1}{2}\left(-\tilde{Z}_{N,t} + \eta\tilde{H}_t + \tilde{\mu}_t\right)^2\right] \\ &+ \gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)E_{t-1}\left[\tilde{\mu}_t - \tilde{\mu}_t^{*} + \tilde{P}_{F,t}^{*} + \frac{1}{2}\left(\tilde{\mu}_t - \tilde{\mu}_t^{*} + \tilde{P}_{F,t}^{*}\right)^2\right]\end{aligned}$$

so that

$$\begin{aligned}
\tilde{\Omega}_{P,t} &= E_{t-1}\gamma_n \left[\tilde{\mu}_t + \frac{1}{2}\left(-\tilde{Z}_{N,t} + \eta\tilde{H}_t + \tilde{\mu}_t\right)^2\right] \\
&+ \gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)E_{t-1}\left[\tilde{\mu}_t + \frac{1}{2}\left(\tilde{\mu}_t - \tilde{\mu}_t^* + \tilde{P}_{F,t}^*\right)^2\right] + \\
&- \frac{1}{2}\left[E_{t-1}\left[\gamma_n\left(-\tilde{Z}_{N,t} + \eta\tilde{H}_t + \tilde{\mu}_t\right) + \gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\left(\tilde{\mu}_t - \tilde{\mu}_t^* + \tilde{P}_{F,t}^*\right)\right]\right]^2 \\
&+ t.i.p.
\end{aligned}$$

Recall that

$$H_t = \left(\left(1-\gamma_v\right)^{(1-\gamma_v)}\left(\gamma_v\right)^{(\gamma_v)}\left(\kappa\mu_t^*\right)^{(1-\gamma_v)-1}P_{H,t}^* Z_{H,t}\left(P_{M,t}^*\right)^{-(1-\gamma_v)}\right)^{\frac{1}{\eta(\gamma_v)}}$$

or

$$\eta\tilde{H}_t = \frac{1}{(\gamma_v)}\left(-\left(\gamma_v\right)\tilde{\mu}_t^* + \tilde{P}_{H,t}^* + \tilde{Z}_{H,t} - (1-\gamma_v)\tilde{P}_{M,t}^*\right)$$

where the approximation involves only first order terms since H_t is a convolution of exogenous AR(1) shocks. Replacing H_t in $\tilde{\Omega}_{P,t}$ and using $\mu_t = S_t\mu_t^*$ we obtain:

$$\begin{aligned}
\tilde{\Omega}_{P,t} &= E_{t-1}\left(\gamma_n + \gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\right)\tilde{S}_t \\
&\quad E_{t-1}\gamma_n\left[\tilde{\mu}_t^* + \frac{1}{2}\left(-\tilde{Z}_{N,t} + \frac{1}{(\gamma_v)}\left(\tilde{P}_{H,t}^* + \tilde{Z}_{H,t} - (1-\gamma_v)\tilde{P}_{M,t}^*\right) + \tilde{S}_t\right)^2\right] \\
&+ \gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)E_{t-1}\left[\tilde{\mu}_t^* + \frac{1}{2}\left(\tilde{S}_t + \tilde{P}_{F,t}^*\right)^2\right] + \\
&- \frac{1}{2}\left[E_{t-1}\left[\gamma_n\left(-\tilde{Z}_{N,t} + \frac{1}{(\gamma_v)}\left(\tilde{P}_{H,t}^* + \tilde{Z}_{H,t} - (1-\gamma_v)\tilde{P}_{M,t}^*\right) + \tilde{S}_t\right)\right.\right. \\
&\quad \left.\left. + \gamma_F\left(1-\gamma_H\right)\left(1-\gamma_n\right)\left(\tilde{S}_t + \tilde{P}_{F,t}^*\right)\right]\right]^2 \\
&+ t.i.p.
\end{aligned} \tag{A.29}$$

Using the result that $E_{t-1}\widetilde{S}_t = 0$ and replacing the first order solution for $\tilde{S}_t$ under the optimal policy gives:

$$\begin{aligned}
E_{t-1}\tilde{\Omega}^{optimal}_{P,t} &= E_{t-1}\gamma_n\left[\tilde{\mu}^*_t + \frac{1}{2}\left(\begin{array}{c} -\tilde{Z}_{N,t} + \frac{1}{\gamma_v}\left(\tilde{P}^*_{H,t} + \tilde{Z}_{H,t} - (1-\gamma_v)\,\tilde{P}^*_{M,t}\right) - \\ (1-\Gamma)\left(-\varepsilon_{N,t} + \dfrac{1}{\gamma_v}\left(\varepsilon^*_{H,t} + \varepsilon_{H,t} - (1-\gamma_v)\,\varepsilon^*_{M,t}\right)\right) - \Gamma\varepsilon^*_{F,t} \end{array}\right)^2\right] \\
&+ \gamma_F\,(1-\gamma_H)\,(1-\gamma_n) \times \\
&\quad E_{t-1}\left[\tilde{\mu}^*_t + \frac{1}{2}\left(\begin{array}{c} -(1-\Gamma)\left(-\varepsilon_{N,t} + \dfrac{1}{\gamma_v}\left(\varepsilon^*_{H,t} + \varepsilon_{H,t} - (1-\gamma_v)\,\varepsilon^*_{M,t}\right)\right) \\ -\Gamma\varepsilon^*_{F,t} + \tilde{P}^*_{F,t} \end{array}\right)^2\right] + \\
&- \frac{1}{2}\left[E_{t-1}\left[\gamma_n\left(-\tilde{Z}_{N,t} + \frac{1}{\gamma_v}\left(\tilde{P}^*_{H,t} + \tilde{Z}_{H,t} - (1-\gamma_v)\,\tilde{P}^*_{M,t}\right)\right) + \gamma_F\,(1-\gamma_H)\,(1-\gamma_n)\left(\tilde{P}^*_{F,t}\right)\right]\right] \\
&+ t.i.p.
\end{aligned}$$

Under the assumption that shocks are not cross correlated, we have:

$$\begin{aligned}
2E_0\tilde{\Omega}^{optimal}_{P,t} &= \gamma_n\left(\left((1-\gamma_n)\,\frac{1}{1-\rho^2}\right) - (1-\Gamma)\right)\tilde{\sigma}^2_N \\
&\quad \gamma_n\left((1-\gamma_n)\,\frac{1}{1-\rho^2} + -(1-\Gamma)\right)\frac{1}{(\gamma_v)^2}\left[\tilde{\sigma}^{2*}_H + \tilde{\sigma}^2_H + (1-\gamma_v)^2\tilde{\sigma}^{*2}_M\right] \\
&+ \left\{\gamma_F\,(1-\gamma_H)\,(1-\gamma_n)\left[(1-\gamma_F\,(1-\gamma_H)\,(1-\gamma_n))\,\frac{1}{1-\rho^2} - \Gamma\right]\right\}\tilde{\sigma}^{*2}_F + \\
&\quad t.i.p
\end{aligned} \tag{A.30}$$

where, WLOG, we assume that all shocks have identical AR(1) coefficient, denoted by ρ. Using eq. (A.29) under the peg ($\widetilde{S}_t = 0$) we have instead:[21]

$$\begin{aligned}
2E_0\tilde{\Omega}^{peg}_{P,t} &= \gamma_n\left((1-\gamma_n)\,\frac{1}{1-\rho^2}\right)\tilde{\sigma}^2_N \\
&\quad \gamma_n\,(1-\gamma_n)\,\frac{1}{1-\rho^2}\frac{1}{(\gamma_v)^2}\left[\tilde{\sigma}^{2*}_H + \tilde{\sigma}^2_H + (1-\gamma_v)^2\tilde{\sigma}^{*2}_M\right] \\
&+ \left\{\gamma_F\,(1-\gamma_H)\,(1-\gamma_n)\left[(1-\gamma_F\,(1-\gamma_H)\,(1-\gamma_n))\,\frac{1}{1-\rho^2}\right]\right\}\tilde{\sigma}^{*2}_F + \\
&\quad t.i.p
\end{aligned} \tag{A.31}$$

[21] To see this, note that all terms in $2E_0\tilde{\Omega}_{P,t+j}$ not multiplied by $\frac{1}{1-\rho^2}$ relate to the exchange rate, and hence disappear under the peg. The term multiplied by 2 also disappears as it relates to the cross product involving the exchange rate.

Finally, adding and subtracting $\log(\tilde{\mu}_t^*) = \log(\mu_t) - \log(S_t)$ from eq.(A.28) we obtain that welfare can be expressed as the sum of terms independent of policy and a linear function of the term $E_0\tilde{\Omega}_{P,t}$. Evaluating welfare using eqs. (A.30) and (A.31), the welfare difference between the optimal policy and peg is then

$$\begin{aligned}\mathcal{W}_0^{optimal} - \mathcal{W}_0^{peg} &= \frac{1}{2}\gamma_n (1-\Gamma)\tilde{\sigma}_N^2 + \\ &\gamma_n (1-\Gamma)\frac{1}{(\gamma_v)^2}\left[\tilde{\sigma}_H^{2*} + \tilde{\sigma}_H^2 + (1-\gamma_v)^2\tilde{\sigma}_M^{*2}\right] + \\ &+\gamma_F (1-\gamma_H)(1-\gamma_n)\Gamma\sigma_F^{*2}\end{aligned} \tag{A.32}$$

Appendix B. Parameterized Model with Capital and Staggered Price Adjustment. Equilibrium conditions

Appendix B.1. First Order Conditions

Define the investment aggregates:

$$I_t^J = \left[(\gamma_{in})^{\frac{1}{\rho_{in}}}\left(I_{N,t}^J\right)^{\frac{\rho_{in}-1}{\rho_{in}}} + (1-\gamma_{in})^{\frac{1}{\rho_{in}}}\left(I_{T,t}^J\right)^{\frac{\rho_{in}-1}{\rho_{in}}}\right]^{\frac{\rho_{in}}{\rho_{in}-1}}, J = N, H \tag{B.1}$$

$$I_{T,t}^J = \left[(\gamma_{ih})^{\frac{1}{\rho_{ih}}}\left(I_{H,t}^J\right)^{\frac{\rho_{ih}-1}{\rho_{ih}}} + (1-\gamma_{ih})^{\frac{1}{\rho_{ih}}}\left(I_{F,t}^J\right)^{\frac{\rho_{ih}-1}{\rho_{ih}}}\right]^{\frac{\rho_{ih}}{\rho_{ih}-1}}, J = N, H \tag{B.2}$$

$$I_{N,t}^J = \left[\int_0^1 \left(I_{N,t}^J\right)^{\frac{\varrho-1}{\varrho}}(z)dz\right]^{\frac{\varrho}{\varrho-1}} \tag{B.3}$$

where the superscript J refers to the sector.

Households' demand functions imply that the composite good price indices can be written as:

$$P_t^c = \left[(\gamma_{cn})(P_{N,t})^{1-\rho_{cn}} + (1-\gamma_{cn})\left(P_{T,t}^c\right)^{1-\rho_{cn}}\right]^{\frac{1}{1-\rho_{cn}}} \tag{B.4}$$

$$P_{T,t}^c = \left[(\gamma_{ch})(P_{H,t})^{1-\rho_{ch}} + (1-\gamma_{ch})(P_{F,t})^{1-\rho_{ch}}\right]^{\frac{1}{1-\rho_{ch}}} \tag{B.5}$$

$$P_{N,t} = \left[\int_0^1 P_{N,t}^{1-\varrho}(z)dz\right]^{\frac{1}{1-\varrho}} \tag{B.6}$$

where P_t^c, $P_{T,t}^c$, and $P_{N,t}$ are the consumer price index (CPI), the price index for T consumption goods, and the price index for N consumption goods, respectively. Investment price indices (P_t^i, $P_{T,t}^i$, and $P_{N,t}$) can be similarly obtained.

The household is assumed to maximize the inter-temporal utility function (29) subject to (26), (27), (28), (B.1), (B.2), (B.3), (30), and the laws of motion for capital in each sector.

The solution to the household decision problem gives the following first order conditions (FOCs):

$$\lambda_t^C = \beta E_t \left\{ \lambda_{t+1}^C \left(1+i_t\right) \frac{P_t^c}{P_{t+1}^c} \right\} \tag{B.7}$$

$$E_t \left\{ \lambda_{t+1}^C \frac{P_t^c}{P_{t+1}^c} \left[\left(1+i_t\right) - \left(1+i_t^*\right) \frac{S_{t+1}}{S_t} \right] \right\} = 0 \tag{B.8}$$

$$\begin{aligned} \lambda_t^C \frac{P_t^i}{P_t^c} Q_t^J = \beta E_t \{ \lambda_{t+1}^C \left(\frac{P_{J,t+1}}{P_{t+1}^c} R_{t+1}^J \right) + \lambda_{t+1}^C \frac{P_{t+1}^i}{P_{t+1}^c} Q_{t+1}^J [\Phi\left(\frac{I_{t+1}^J}{K_t^J}\right) \\ - \frac{I_{t+1}^J}{K_t^J} \Phi'\left(\frac{I_{t+1}^J}{K_t^J}\right) + (1-\delta)]\}, \quad J{=}N,H \end{aligned} \tag{B.9}$$

$$Q_t^J = \left[\Phi'\left(\frac{I_t^J}{K_{t-1}^J} \right) \right]^{-1} \qquad J = N,H \tag{B.10}$$

$$C_{N,t} = \frac{\gamma_{cn}}{1-\gamma_{cn}} \left(\frac{P_{T,t}^c}{P_{N,t}} \right)^{\rho_{cn}} C_{T,t} \quad ; \quad C_{H,t} = \frac{\gamma_{ch}}{1-\gamma_{ch}} \left(\frac{P_{F,t}}{P_{H,t}} \right)^{\rho_{ch}} C_{F,t} \tag{B.11}$$

$$I_{N,t}^J = \frac{\gamma_{in}}{1-\gamma_{in}} \left(\frac{P_{T,t}^i}{P_{N,t}} \right)^{\rho_{in}} I_{T,t}^J \quad ; \quad I_{H,t}^J = \frac{\gamma_{ih}}{1-\gamma_{ih}} \left(\frac{P_{F,t}}{P_{H,t}} \right)^{\rho_{ih}} I_{F,t}^J, \quad J = N,H \tag{B.12}$$

$$\lambda_t^C \frac{W_t^N}{P_t^c} = \ell \left(H_t\right)^{\eta_H} \quad ; \quad \lambda_t^C \frac{W_t^H}{P_t^c} = \ell \left(H_t\right)^{\eta_H} \tag{B.13}$$

where $\lambda_t^C = \frac{1}{C_t}$ is the marginal utility of total consumption and $(1+i_t) = \frac{1}{v_t}$. Eqs. (B.7) to (B.10) are the Euler equations for the assets available to households, where Q_t^J is Tobin's Q. The conditions in (B.11) and (B.12) give the optimal choice for consumption and investment across goods. The labor supply optimality conditions in (B.13) imply that $\frac{W_t^N}{P_t^c} = \frac{W_t^H}{P_t^c}$, a consequence of costless labor mobility across sectors.

Cost minimization in the non-tradable sector implies:

$$\frac{W_t^N}{P_{N,t}} = MC_t^N(z) \left[1-\alpha_n\right] \left(\gamma_{nv}\right)^{\frac{1}{\rho_{nv}}} \frac{V_{N,t}(z)}{H_t^N(z)} \left(\frac{Y_{N,t}(z)}{V_{N,t}(z)} \right)^{\frac{1}{\rho_{nv}}} \tag{B.14}$$

$$R_t^N = MC_t^N(z) \alpha_N \left(\gamma_{nv}\right)^{\frac{1}{\rho_{nv}}} \frac{V_{N,t}(z)}{K_{t-1}^N(z)} \left(\frac{Y_{N,t}(z)}{V_{N,t}(z)} \right)^{\frac{1}{\rho_{nv}}} \tag{B.15}$$

$$\frac{P_{M,t}}{P_{N,t}} = MC_t^N(z) \left(1-\gamma_{nv}\right)^{\frac{1}{\rho_{nv}}} \left(\frac{Y_{N,t}}{M_{N,t}} \right)^{\frac{1}{\rho_{nv}}} \tag{B.16}$$

where $MC_t^N(z)$ is the real marginal cost for firm z and $P_{M,t}$ is the domestic currency price of the imported intermediate good.

Cost minimization in the tradable sector gives the factor demands:

$$\frac{W_t^H}{P_{H,t}} = (1-\alpha_h)\,(\gamma_v)^{\frac{1}{\rho v}}\,\frac{V_{H,t}}{H_t^H}\left(\frac{Y_{H,t}}{V_{H,t}}\right)^{\frac{1}{\rho v}} \tag{B.17}$$

$$R_t^H = \alpha_h\,(\gamma_v)^{\frac{1}{\rho v}}\,\frac{V_{H,t}}{K_{t-1}^H}\left(\frac{Y_{H,t}}{V_{H,t}}\right)^{\frac{1}{\rho v}} \tag{B.18}$$

$$\frac{P_{M,t}}{P_{H,t}} = (1-\gamma_v)^{\frac{1}{\rho v}}\left(\frac{Y_{H,t}}{M_{H,t}}\right)^{\frac{1}{\rho v}} \tag{B.19}$$

Appendix B.2. Market Clearing

We assume government purchases a fixed amount $G_{N,t}$ of N goods. The resource constraint in the nontradable and domestic tradable sector is given by

$$Y_{N,t} = (C_{N,t} + I_{N,t}^N + I_{N,t}^H + G_{N,t})\int_0^1\left[\frac{P_{N,t}(z)}{P_{N,t}}\right]^{-\varrho} dz \tag{B.20}$$

$$Y_{H,t} = AB_{H,t} + C_{H,t}^* \tag{B.21}$$

$$AB_{H,t} = C_{H,t} + I_{H,t}^N + I_{H,t}^H \tag{B.22}$$

where $AB_{H,t}$ is domestic absorption and $C_{H,t}^*$ are net exports of the H good.

The trade balance, expressed in units of good H, can be written as

$$NX_{H,t} = C_{H,t}^* - \frac{P_{F,t}}{P_{H,t}}X_{F,t} - \frac{P_{M,t}}{P_{H,t}}(M_{H,t} + M_{N,t}) \tag{B.23}$$

where $X_{F,t} = \int_0^1 Y_{F,t}(z)dz = Y_{F,t}$. With complete pass-through, it holds: $Y_{F,t} = X_{F,t} = (C_{F,t} + I_{F,t}^N + I_{F,t}^H)$. Assuming that domestic bonds are in zero net supply, the current account (in nominal terms) reads as

$$S_t B_t^* = \left(1 + i_{t-1}^*\right) S_t B_{t-1}^* + P_{H,t} NX_{H,t} \tag{B.24}$$

Finally, labor market clearing requires

$$H_t^d = H_t^N + H_t^H = H_t^s \tag{B.25}$$

Using the aggregate consumption good as numeraire, we obtain the total value added in the economy as:

$$GDP_t^c = \frac{P_{N,t}Y_{N,t} + P_{H,t}Y_{H,t}}{P_t^c} - (M_{H,t} + M_{N,t})S_{M,t}\frac{P_H}{P_t^c} \tag{B.26}$$

Following Schmitt-Grohé and Uribe (2003), the nominal interest rate at which households can borrow internationally is given by the exogenous world interest rate $\tilde{\imath}^*$ plus a premium, which is assumed to be increasing in the real value of the country's stock of foreign debt:

$$(1 + i_t^*) = (1 + \tilde{\imath}_t^*)g(-B_{H,t}) \tag{B.27}$$

where $B_{H,t} = \frac{S_t B_t^*}{P_{H,t}}$ and $g(\cdot)$ is a positive, increasing function. Eq. (B.27) ensures the stationarity of the model.

Appendix C. Parameterized Model with Capital and Staggered Price Adjustment. Baseline parameterization

We assume the values for $\gamma_{ch},\ \gamma_{ih},\ \gamma_v, \gamma_{cn},\ \gamma_{in},\ \rho_{cn},$ and ρ_{in} are equal to the estimates obtained from input-output tables data for the Czech Republic. Table 2 reports these benchmark values. The remaining parameters are in line with the international business cycle literature and with macroeconomic evidence for OECD countries. The elasticity of substitution ρ_v between the imported intermediate good $X_{H,t}$ and domestic value added $V_{H,t}$ is set equal to 0.5 . We assume that the foreign and domestic goods in the tradable consumption and investment index are closer substitutes, and set $\rho_{ih},\ \rho_{ch}$ equal to 2. The quarterly discount factor β is set equal to 0.99, which implies a steady-state real world interest rate of 4 percent in a steady state with zero inflation. The elasticity of labor supply is set equal to $\frac{1}{2}$, and the ratio of average hours worked relative to total hours equal to $\frac{1}{3}$. We assume 40 percent of domestic nontradable output is absorbed by the government sector in steady state, while no tradable goods is purchased by the government. This (approximately) consistent with OECD input-output data. The elasticity of Tobin's Q with respect to the investment-capital ratio is set equal to 0.5 . We assume there are no capital adjustment costs in steady state. The quarterly depreciation rate of capital, δ, is assigned the value of 0.025. Following Cook and Devereux (2006) the tradable sector is assumed to be more capital-intensive than the nontradable sector, with $\alpha_h = 0.67$ and $\alpha_n = 0.33$. The speed of price-adjustment in the nontradable sector is assumed to be slower than in the US, and on the upper end of estimates for European countries reported by Galí et al. (2001). The unconditional probability $(1-\vartheta)$ of adjusting prices in any period is set equal to 0.2. With larger values, CPI inflation would be too volatile, given the estimate for the shares of nontradable consumption and investment goods. The steady-state mark-up in the nontradable sector is set equal to 10 percent, consistent with macroeconomic evidence for OECD countries. The markup and the price-adjustment speed in the consumption good import sector are assumed identical to the non-traded good sector.

The monetary authority adjusts the nominal interest rate according to the rule:

$$(1+i_t) = \left[\left(\frac{1+\pi_t}{1+\pi_{ss}} \right)^{\omega_\pi} \left(\frac{e_t}{e_{ss}} \right)^{\omega_e} \left(\frac{Y_t}{Y_{ss}} \right)^{\omega_Y} \right]^{(1-\chi)} [(1+i_{t-1})]^{\chi} \varepsilon_{i,t} \tag{C.1}$$

where ω_π , $\omega_e, \omega_Y \geq 0$ are the feedback coefficients to CPI inflation, nominal exchange rate, and GDP in units of domestic consumption aggregate (Y_t), $\chi \in [0,1)$ is the degree of smoothing and $\varepsilon_{i,t}$ is an exogenous shock to monetary policy. The subscript ss indicates the steady-state value of a variable. We set $\omega_\pi = 1$, $\omega_Y = 0.4, \omega_e = 0.1$, $\chi = 0.8$.

The parameterization of the exogenous stochastic processes ensures that he business cycle properties of the model economy are consistent with data on small open emerging market economies. The resulting values are in line with the recent literature on micro-founded open-economy model with nominal rigidities (Galí and Monacelli, 2005, Kollmann, 2002, Kollmann, 1997, Laxton and Pesenti, 2003, Monacelli, 2005).The exogenous stochastic processes for the total factor productivity shock in the tradable and nontradable good sector, the household preference shifter, the foreign-currency price of the tradable goods H and F and the imported intermediate input, and the foreign interest rate follow an AR(1) specification in logs:

$$a_t^H = \rho_{a^H} a_{t-1}^H + \varepsilon_{a^H,t}$$
$$a_t^N = \rho_{a^N} a_{t-1}^N + \varepsilon_{a^N,t}$$
$$d_t = \rho_d d_{t-1} + \varepsilon_{d,t}$$
$$p_{H,t}^* = \rho_{p_H} p_{H,t-1}^* + \varepsilon_{p_H,t}$$
$$p_{F,t}^* = \rho_{p_F} p_{F,t-1}^* + \varepsilon_{p_F,t}$$
$$p_{M,t}^* = \rho_{p_M} p_{M,t-1}^* + \varepsilon_{p_M,t}$$
$$i_t^* = \rho_{i^*} i_{t-1}^* + \varepsilon_{i^*,t}$$

where $\varepsilon_{j,t}$ is normally distributed with variance $\sigma_{\varepsilon_j}^2$. The productivity shock innovation volatility is set in both sectors equal to $\sigma_a = 0.008$ with $\rho_a = 0.95$. These values are in line with the international business cycle literature, and close to the ones in Gali and Monacelli (2005) and to the average estimate in Kollman (2002) for UK, Japan, Germany over the 1973-1994 sample. The coefficients for the unobservable preference shock process d_t are left as free parameters, and are adjusted to ensure sufficient volatility in domestic output. We set $\rho_d = 0.85$ and $\sigma_d = 0.009$. These values are larger than those in Laxton and Pesenti (2003) ($\rho_d = 0.7$ and $\sigma_d = 0.004$) and similar to the values reported by Monacelli (2005). To parameterize the process for the foreign interest rate we use Eurostat data on the average money market rate in the EU-15, resulting in estimates of $\rho_{i^*} = 0.95$ and $\sigma_{i^*} = 0.001$. The exogenous innovation $\varepsilon_{i,t}$ in the monetary policy rule follows an i.i.d. process, and its standard deviation is set at $\sigma_i = 0.001$.

To parameterize the stochastic process for the foreign prices we use data for the Czech Republic over the period 1994-2002. The time series for p_j^*, $j = F, M$, is obtained from detrended import commodity price indices converted in units of foreign currency (euro) using the nominal effective exchange rate . The weights for the foreign intermediate and consumption goods' price indices are the 1997-2006 average Commodity Composition of Imports as reported by IMF (2002), the Czech Statistical Office, and the Czech National Bank (July 2006 data). p_H^* is obtained from the aggregate export price index converted in units of foreign currency using the nominal effective exchange rate.

Under the baseline parameterization the volatility of output in percentage terms is 2.64 . Neumeyer and Perri (2005) find an average GDP volatility for Argentina, Brazil, Korea, Mexico, and the Philippines equal to 2.79 percent over the period 1994-2001. Among the eight Central and Eastern European new EU members, GDP volatility ranged from 0.72 percent (Hungary) to 2.83 percent (Lithuania) in the 1998-2002 period (Darvas and Szapary, 2004).

The standard deviation of consumption and net exports is equal to 2.9 and 1.8 (respectively 3.63 and 2.40 across five emerging markets economies, Neumeyer and Perri, 2005). The policy rule implies a large volatility for the nominal exchange rate, equal to 8 percent (Kollmann, 1997 reports an average value of 9.13 percent for Japan, UK, and Germany over the 1973-1994 period).

The volatility of inflation for the composite of tradable goods is 0.68, more than twice as large as the volatility of the nontradable good inflation (0.31), owing to the larger share of flexible prices in the tradable good sector. The volatility for CPI inflation is equal to 0.55.

References

Adão, B., Correia, I., Teles, P., 2003. Gaps and triangles. Review of Economic Studies 70, 699–713.

Bems, R., 2008. Aggregate investment expenditures on tradable and nontradable goods. Review of Economic Dynamics 11 (4), 852–883.

Benigno, P., Woodford, M., November 2006. Linear-Quadratic Approximation of Optimal Policy Problems. NBER, Working Paper No. 12672.

Betts, C. M., Kehoe, T., 2001. Tradability of Goods and Real Exchange Rate Fluctuations. Federal Reserve Bank of Minneapolis Staff Report.

Calvo, G. A., 1983. Staggered Prices in a Utility-Maximizing Framework. Journal of Monetary Economics 12, 383–98.

Chari, V., Kehoe, P., McGrattan, E. R., 2002. Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates? Review of Economic Studies 69 (3), 533–563.

Coenen, G., Lombardo, G., Smets, F., Straub, R., 2009. International Transmission and Monetary Policy Coordination. In: Galí, J., Gertler, M. (Eds.), International Dimensions of Monetary Policy. University Of Chicago Press.

Cook, D., Devereux, M. B., 2006. Accounting for the East Asian crisis: a quantitative model of capital outflows in small open economies. Journal of Money, Credit, and Banking 38 (3), 721.

Corsetti, G., March 2006. Openness and the case for flexible exchange rates. Research in Economics 60 (1), 1–21.

Corsetti, G., Dedola, L., Leduc, S., September 2008. High Exchange-Rate Volatility and Low Pass-Through. Journal of Monetary Economics 55 (6), 1113–1128.

Corsetti, G., Dedola, L., Leduc, S., 2010a. Optimal monetary policy and the sources of local-currency price stability. In: Galí, J., Gertler, M. (Eds.), International Dimensions of Monetary Policy. NBER Chapters. The University of Chicago Press, pp. 319–367.

Corsetti, G., Dedola, L., Leduc, S., October 2010b. Optimal monetary policy in open economies. In: Friedman, B. M., Woodford, M. (Eds.), Handbook of Monetary Economics. Vol. 3 of Handbook of Monetary Economics. Elsevier, Ch. 16, pp. 861–933.

Corsetti, G., Dedola, L., Leduc, S., 2012. Demand imbalances, exchange rate misalignment and monetary policy. Mimeo.

Corsetti, G., Pesenti, P., May 2001. Welfare and Macroeconomic Interdependence. Quarterly Journal of Economics 116, 421–45.

Corsetti, G., Pesenti, P., 2005. International dimensions of optimal monetary policy. Journal of Monetary Economics 52 (2), 281–305.

Darvas, Z., Szapary, G., 2004. Business cycle synchronization in the enlarged eu: Comovements in the new and old members. MNB Working Paper 2004/1.

De Gregorio, J., Giovannini, A., Wolf, H., 1994. International evidence on tradables and nontradables inflation. European Economic Review 38 (6), 1225–1244.

De Paoli, B., 2009a. Monetary policy and welfare in a small open economy. Journal of International Economics 77 (1), 11–22.

De Paoli, B., 2009b. Monetary policy under alternative asset market structures: The case of a small open economy. Journal of Money Credit and Banking 41, 1301–1330.

Devereux, M. B., Engel, C., 2002. Exchange Rate Pass-through, Exchange Rate Volatility, and Exchange Rate Disconnect. Journal of Monetary Economics 49 (5), 913–940.

Devereux, M. B., Engel, C., 2003. Monetary Policy in the Open Economy Revisited: Price Setting and Exchange-Rate Flexibility. Review of Economic Studies 70 (4), 765–783.

Devereux, M. B., Engel, C., 2007. Expenditure Switching Versus Real Exchange Rate Stabilization: Competing Objectives for Exchange Rate Policy. Journal of Monetary Economics 54 (8), 2346–2374.

Dotsey, M., Duarte, M., September 2008. Nontraded Goods, Market Segmentation, and Exchange Rates. Journal of Monetary Economics 55 (6), 1129–1142.

Duarte, M., Obstfeld, M., October 2008. Monetary Policy in the Open Economy Revisited: The Case for Exchange-Rate Flexibility Restored. Journal of International Money and Finance 27 (6), 949–957.

Engel, C., October 2011. Currency Misalignments and Optimal Monetary Policy: A Reexamination. American Economic Review 101, 2796–2822.

Engel, C., Wang, J., 2010. International trade in durable goods: Understanding volatility, cyclicality, and elasticities. Journal of International Economics In Press.

Faia, E., Monacelli, T., 2008. Optimal Monetary Policy in a Small Open Economy with Home Bias. Journal of Money, Credit and Banking 40 (4), 721–750.

Friedman, M., 1953. The case for flexible exchange rates. In: Essays in Positive Economics. The University of Chicago Press, Chicago, pp. 157–203.

Galí, J., Gertler, M., Lopez-Salido, J. D., 2001. European inflation dynamics. European Economic Review 45 (7), 1237 – 1270.

Galí, J., Monacelli, T., 07 2005. Monetary Policy and Exchange Rate Volatility in a Small Open Economy. Review of Economic Studies 72 (3), 707–734.

IMF, 2002. Statistical Appendix. Czech Republic Country Report No. 02/168.

Khan, A., King, R., Wolman, A., 2003. Optimal monetary policy. Review of Economic Studies 70(4), 825–860.

Kollmann, R., 1997. The Exchange Rate in a Dynamic-Optimizing Current Account Model with Nominal Rigidities: a Quantitative Investigation. Journal of International Economics 55, 243–262.

Kollmann, R., 2002. Monetary policy rules in the open economy: effects on welfare and business cycles. Journal of Monetary Economics 49 (5), 989–1015.

Laxton, D., Pesenti, P., July 2003. Monetary rules for small, open, emerging economies. Journal of Monetary Economics 50 (5), 1109–1146.

Lombardo, G., Ravenna, F., 2012. The size of the tradable and non-tradable sectors: Evidence from input–output tables for 25 countries. Economics Letters 116 (3), 558–561.

Lombardo, G., Sutherland, A. J., February 2007. Computing Second-Order-Accurate Solutions for Rational Expectation Models using Linear Solution Methods. Journal of Economic Dynamics and Control 31 (2), 515–530.

Mendoza, E. G., 1995. The Terms of Trade,the Real Exchange Rate, and Economic Fluctuations. International Economic Review 36, 101–137.

Monacelli, T., 2005. Monetary Policy in a Low Pass-Through Environment. Journal of Money Credit and Banking 37, 1047–1066.

Mundell, R., 1961. A theory of optimum currency areas. The American Economic Review, 657–665.

Neumeyer, P. A., Perri, F., March 2005. Business Cycles in Emerging Economies: The Role of Interest Rates. Journal of Monetary Economics 52 (2), 345–380.

Obstfeld, M., Rogoff, K., August 2000. New Directions for Stochastic Open Economy Models. Journal of International Economics 50 (1), 117–53.

Pesenti, P., Tille, C., July 2004. Stabilization, Competitiveness, and Risk-Sharing: A Model of Monetary Interdependence. National Centre of Competence in Research Financial Valuation and Risk Management, Working Paper No 191.

Ravenna, F., Natalucci, F. M., 2008. Monetary Policy Choices in Emerging Market Economies: The Case of High Productivity Growth. Journal of Money, Credit and Banking 40 (2-3), 243–271.

Schmitt-Grohé, S., Uribe, M., 2003. Closing Small Open Economy Models. Journal of International Economics 61(1), 163–185.

Schmitt-Grohé, S., Uribe, M., 2004. Optimal Fiscal and Monetary Policy under Sticky Prices. Jounal of Economic Theory 114, 198–203.

Shi, K., Xu, J., Oct. 2008. Input Substitution, Export Pricing, and Exchange Rate Policy. Working Papers 102008, Hong Kong Institute for Monetary Research.

Smets, F., Wouters, R., 2002. Openness, imperfect exchange rate pass-through and monetary policy. Journal of monetary Economics 49 (5), 947–981.

Sutherland, A., 2005. Incomplete pass-through and the welfare effects of exchange rate variability. Journal of international economics 65 (2), 375–399.

Sutherland, A. J., 2006. The Expenditure Switching Effect, Welfare and Monetary Policy in a Small Open Economy. Journal of Economic Dynamics and Control 30, 1159–1182.

Woodford, M., 2003. Interest and Prices: Foundations of a Theory of Monetary Policy. Princeton U.P., Princeton, NJ.