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Abstract

The U.S. dollar plays a key role in international trade invoicing along two complementary dimensions. First, most U.S. exports and imports are invoiced in dollars; second, trade flows that do not involve the United States are often invoiced in dollars, a fact that has received relatively little attention. Using a simple center-periphery model, we show that the second dimension magnifies the exposure of periphery countries to the center's monetary policy, even when direct trade flows between the center and the periphery are limited. When intra-periphery trade volumes are sensitive to the center's monetary policy, the model predicts substantial welfare gains from coordinated monetary policy. Our model also shows that although exchange rate movements are not fully efficient, flexible exchange rates are a central component of optimal monetary policy.

Key words: exchange rate, pass-through, center-periphery, invoicing, monetary policy, interdependence

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1 Introduction

The prominent role of the U.S. dollar in the invoicing of international trade transaction is a major feature of the global economy.[1] Its role encompasses two dimensions presented in Goldberg and Tille (2005). The first relates to trade flows to and from the United States, which are overwhelmingly invoiced in dollars. The second dimension is its sizable role as a 'vehicle invoicing currency' in trade flows that do not involve the United States.

This paper analyzes how these two dimensions of the international role of a vehicle currency affect the international transmission of shocks and policy, with a focus on the second dimension that has received a limited attention in the literature despite its empirical relevance. International trade invoicing is recognized as a central aspect in international economics, as it affects the extent to which exchange rate movements impact international relative prices, the so-called exchange rate pass-through, and lead to demand switches across goods produced in different countries. This in turn is a central element in the design of monetary policy in open economies.[2]

Most existing studies focus on a symmetric setting where the degree of exchange rate pass-through is the same for all trade flows. Evidence of asymmetry in exchange rate pass-through, however, abounds between the U.S. and the Euro area countries with their respective trade partners, as documented by Campa and Goldberg (2005), Faruque (2006), and Ihrig et al (2006). Some contributions consider such asymmetries and show substantial implications for the design of policy (Corsetti and Pesenti 2005a,b, Devereux, Shi, and Xu 2006). These contributions focus on two-country models which only encompass the first dimension of the international role of a currency.

This paper analyzes both dimensions of the international role of a currency by considering a simple center-periphery model. Five main results emerge. First, monetary policy in the center has a disproportionately large effect on worldwide consumption in the presence of an international role for its currency. This effect is more pronounced when the role extends to the second dimension, in which case it is observed even in the absence of direct trade flows between the center and the periphery. Second, the impact of productivity shocks on the welfare of the various countries is affected by the international role of the center currency, even though the optimal monetary policy rules in a non-cooperative setting are not. This aspect reflect externalities of the monetary policy in the center on the periphery countries. For instance, the center policy can lead to inefficient price movements be-

[1] While the dollar also plays a major role in international reserve holdings and financial markets, our analysis focuses on the invoicing of trade.

[2] A non-exhaustive list includes Corsetti and Pesenti (2005a), Engel and Devereux (2003), Obstfeld and Rogoff (2002).

tween the periphery countries under the second dimension. Third, the model predicts substantial gains from policy cooperation because of these externalities. Whether the cooperative policy requires the center monetary policy to be more or less targeted to its domestic shocks depend on the exact nature of the international role of its currency. Fourth, while both periphery countries gain from cooperation, the gain is likely to be higher for the country which experiences the least volatile shocks and the center has lower welfare. Fifth, even though exchange rate movements can entail an inefficient component, exchange rate pegs are not desirable in our model.

Our emphasis on the international role of the dollar in intra-periphery trade is consistent with the insights of Cook and Devereux (2006). They consider a partial equilibrium model where the center is taken as exogenous, and apply it to the East Asian crisis of 1997-1998. Their results point to the role of the dollar in intra-Asia trade as a central feature in accounting for the magnitude and persistence of the crisis.

The paper is organized as follows. Section 2 presents empirical evidence on the international invoicing role of the dollar and euro. Section 3 presents a simple center-periphery model. Section 4 explores the design of optimal monetary policy in a stochastic setup, with a numerical illustration of the main results. Section 5 concludes and reviews potential extensions of our simple setup.

2 Evidence on vehicle currency use in international trade

Our focus on vehicle currency use in international trade is highly relevant in light of the international role of the dollar and the emerging role of the euro. These are documented in Tables 1 and 2, which present data on invoicing from Goldberg and Tille (2005) and ECB publications, and on international trade transactions.

Table 1 documents the international use of the dollar as an invoicing currency. Column (1) shows the share of exports invoiced in dollar for several countries. Column (2) presents the share of exports going to the United States, while column (3) shows the share of exports sold to the United States and "dollar bloc" countries which keep their currency stable vis-a-vis the dollar. Column (3)-(6) show the corresponding numbers on the import side, providing evidence of dollar use in intra-periphery trade.

Looking across countries, the use of the dollar in invoicing goes well beyond the role of the United States as a direct trade counterparty. While adding exports to the dollar block countries reduces the discrepancy for some countries, a large gap remains between the use of the dollar and the share

of exports to dollar bloc countries. The vehicle currency role of the dollar is especially striking for Asian countries: more than 80 percent of the exports of Korea, Malaysia and Thailand are invoiced in dollars, while the United States accounts for at most one-fifth of these countries exports, and export to dollar countries account for between one-third and one half of their trade. A similar pattern is observed for Eastern European accession countries. Cook and Devereux (2006) similarly emphasize the role of the dollar in the invoicing of trade between Asian countries. The data on imports show a similar pattern, perhaps relecting dollar use in invoicing trade in commodities and raw materials.

Table 2 shows a similar exercise for the use of the euro as an invoicing currency. The values for the countries in the Euro area in column (1) and (4) are for the trade flows outside the Euro Area, and the values in columns (3) and (6) are only for the "euro block" countries. The table shows that Asian economies seldom use euros for invoicing export or import transactions. Country proximity to the euro area plays a substantial role in explaining the use of euros in international trade transactions, as does the possibility of joining the euro area.[3] For these countries, trade with the center and other periphery countries are largely conducted in euros.

3 A simple center-periphery model

3.1 Geographical structure and timing

We use a three-country variant of the workhorse 'new open economy macroeconomics' model introduced by Obstfeld and Rogoff (1995), focusing on the novel elements and the corresponding intuitive interpretations.[4] The world is comprised of three countries: A, B, and C. Country A represents a "center" country, while countries B and C are "periphery" countries. We focus on symmetric sizes between the center and the periphery, as well as within the periphery. Country A accounts for half the world, while each periphery country represents a quarter of the world. There is a continuum of differentiated brands available for consumption, indexed along a unit interval. Firms in country A produce brands on the $0 - 0.5$ interval, firms in country B produce brands on the $0.5 - 0.75$ interval, and firms in country C produce brands on the $0.75 - 1$ interval.

Each country is inhabited by a representative consumer who purchases all brands available in the world economy. In terms of notation, consumption levels are indexed with a subscript for the country where consumption takes

[3] Goldberg and Tille (2006), Goldberg (2007), ECB (2006), Kamps (2006),

[4] A detailed exposition of the technical steps is found in an Appendix available on request

place, and a superscript for the country where the good is produced. Specifically, $C_i^j(z)$ is the consumption in country i of the brand z produced in country j. Individual brands are aggregated into indexes, as detailed below, and C_i^j is the consumption in country i of the index of all brands produced in country j. The indexes themselves are aggregated further into the overall consumption, with C_i being the overall consumption index in country i.

The prices of the various goods are indexes along similar lines. $P_i^j(z)$ is the price paid by the consumers in country i for each unit of brand z produced in country j. The prices of the various brands produced in a given country are aggregated into a country-of-origin price index, with P_i^j being the price index charged in country i for the brands produced in country j. These indexes are in turn aggregated in the overall consumer price index P_i. Prices are expressed in the currency of the country where the goods are consumed, namely i.

We consider a one-period stochastic model. The good-producing firms set their prices at the beginning of the period. The various shocks then occur, and the monetary authorities react to them, leading to movements in exchange rates and, possibly, import prices. Consumption and production then take place. The ex-post output is demand-driven, with firms meeting the demand they face at their preset prices. While firms set prices ex-ante and cannot adjust them following shocks, their forward-looking pricing takes account of the potential distribution of shocks and the monetary policy rules. [5]

3.2 Consumption allocation

We allow for home bias in consumption between the center and periphery goods. Specifically, the representative consumer in country A allocates her overall consumption across the various brands to maximize the following index:

$$C_A = (\alpha)^{-\alpha} \left(\frac{1-\alpha}{2}\right)^{-(1-\alpha)} \left(C_A^A\right)^{\alpha} \left(C_A^B C_A^C\right)^{\frac{1-\alpha}{2}} \tag{1}$$

[5] While our static model can appear restrictive, the functional forms used imply that a dynamic version boils down to a succession of static models (Corsetti and Pesenti 2005a). The functional form also ensures full international risk sharing.

The elasticity of substitution between goods produced in different countries is set at one. The sub-index by country of origin are given by:

$$\begin{aligned} C_A^A &= \left[(2)^{\frac{1}{\lambda}} \int_0^{0.5} \left(C_A^A(z)\right)^{\frac{\lambda-1}{\lambda}} dz\right]^{\frac{\lambda}{\lambda-1}} \\ C_A^B &= \left[(4)^{\frac{1}{\lambda}} \int_{0.5}^{0.75} \left(C_A^B(z)\right)^{\frac{\lambda-1}{\lambda}} dz\right]^{\frac{\lambda}{\lambda-1}} \\ C_A^C &= \left[(4)^{\frac{1}{\lambda}} \int_{0.75}^{1} \left(C_A^C(z)\right)^{\frac{\lambda-1}{\lambda}} dz\right]^{\frac{\lambda}{\lambda-1}} \end{aligned}$$

$\lambda > 1$ is the elasticity of substitution between brands produced in the same country. Similarly, the representative consumer in a periphery country B or C allocates her consumption across the various brands to maximize:

$$C_i = (1-\alpha)^{-(1-\alpha)} \left(\frac{\alpha}{2}\right)^{-\alpha} \left(C_i^A\right)^{1-\alpha} \left(C_i^B C_i^C\right)^{\frac{\alpha}{2}} \qquad i = B,\, C \qquad (2)$$

The coefficient $\alpha \in [0.5, 1]$ in (1)-(2) reflects the degree of home bias, in terms of periphery vs. center goods. It plays a central role by allowing us to vary the degree of integration between the center and the periphery. One extreme ($\alpha = 0.5$) corresponds to a fully integrated world where consumers in all countries have similar consumption baskets. The other extreme ($\alpha = 1$) corresponds to a disconnected world characterized by the absence of trade between the center and the periphery. Under intermediate values of α, the consumer in the center countries purchases mostly domestic goods, while the basket of consumers in either periphery country is tilted towards periphery-made goods. The home bias is defined solely in terms of center vs. periphery, and there is no corresponding bias between goods produced within the periphery.

The allocation of consumption is computed following the usual steps and reflects relative prices. For instance, the allocation of purchases by the consumer in country A is:

$$\begin{aligned} C_A^A(z) &= 2\alpha \left[\frac{P_A^A(z)}{P_A^A}\right]^{-\lambda} \left[\frac{P_A^A}{P_A}\right]^{-1} C_A \\ C_A^j(z) &= 2(1-\alpha) \left[\frac{P_A^j(z)}{P_A^j}\right]^{-\lambda} \left[\frac{P_A^j}{P_A}\right]^{-1} C_A \qquad j = B,\, C \end{aligned}$$

where the consumer price index in country A is:

$$P_A = \left(P_A^A\right)^{\alpha} \left(P_A^B P_A^C\right)^{\frac{1-\alpha}{2}} \qquad (3)$$

The price indexes represent the minimal expenditure required to purchase one unit of the corresponding index. The allocation of consumption in country B and C is computed along similar lines, with the consumer price index in a periphery country given by:

$$P_i = \left(P_i^A\right)^{1-\alpha} \left(P_i^B P_i^C\right)^{\frac{\alpha}{2}} \qquad i = B, C \tag{4}$$

3.3 Money and effort

The consumer in country i maximizes a simple utility function over consumption, real balances and hours worked:

$$U_i = E\left[\ln\left(C_i\right) + \chi \ln\left(\frac{M_i}{P_i}\right) - \kappa H_i\right] \qquad i = A,\, B,\, C \tag{5}$$

where E denotes the expectation operator from the point of view of the beginning of the period. C_i is the aggregate consumption index, M_i/P_i denotes real money balances and H_i denotes the hours worked by the consumer. χ and κ are scaling parameters. The simple functional form in (5) allows us to derive our results with a minimal amount of technical complexity. The budget constraint faced by the consumer is:

$$P_i C_i + M_i = \Pi_i + W_i H_i - T_i \tag{6}$$

where Π_i denotes the profits of the firms in country i, which are owned by the local consumer, W_i is the wage rate, and T_i is a lump-sum tax paid to the government of country i.[6] The first-order conditions with respect to real balances and hours worked lead to the money demand and labor supply:

$$M_i = \chi P_i C_i \qquad W_i = \kappa P_i C_i = (\kappa/\chi)\, M_i \tag{7}$$

3.4 Structure of pricing

We choose to focus on how alternative patterns of trade invoicing alter the transmission of monetary policy and its optimal design, and take the pattern of invoicing to be exogenous throughout the paper. While a growing literature has focused on the determinants of invoicing the models considered go beyond our simple setup.[7] For instance, the literature points to a key role for decreasing returns to scale in invoicing decisions. A convex cost of production implies that volatile demand translates into a high marginal cost on average, giving firms an incentive to stabilize demand through their invoicing

[6] Without loss of generality we assume that initial cash holdings are zero.

[7] See for instance Bacchetta and vanWincoop (2005), Devereux, Engel and Storegaard (2004), Goldberg and Tille (2005).

strategy. We abstract from this aspect and consider constant returns to scale to keep the technical complexity to a minimum.[8] Encompassing endogenous invoicing choice in our analysis would require a richer model, a step that we leave for future research.

Firms set the price for domestic sales in the domestic currency. We denote the price set by a firm located in country j for domestic sales by $\tilde{P}_j^j(z)$. By contrast, prices for sales abroad can be invoiced in different currencies. Specifically, a firm invoices its export in a basket currency that consists of the currencies of all three countries. The weights of the currencies in the basket, which are restricted to be in the $[0,1]$ interval, are denoted by γ with a subscript indicating the country of destination, as well as superscripts indicating the country of production and the currency of invoicing. Specifically $\gamma_i^{j,\,\text{cur}\,k}$ is the share of currency k in the invoicing of exports from country j to country i. These exogenous invoicing weights are the same for all firms in the exporting country. The price paid by the consumer in country i, in her own currency, then consists of the preset price in the basket currency, $\tilde{P}_i^j(z)$, as well as a combination of realized exchange rates that reflect the invoicing basket:

$$P_i^j(z) = \tilde{P}_i^j(z) \sum_{k=A,B,C} \left(\frac{S_k}{S_i}\right)^{\gamma_j^{i,\,\text{cur}\,k}} = \tilde{P}_i^j(z) (S_i)^{-1} (S_B)^{\gamma_i^{i,\,\text{cur}\,B}} (S_C)^{\gamma_i^{i,\,\text{cur}\,C}} \tag{8}$$

where S_i is the exchange rate between the center's currency A and currency i. It is expressed as the amount of currency A per unit of currency i, so an increase corresponds to a bilateral depreciation of currency A. The exchange rate between currency i and currency k, in terms of the amount of currency i per unit of currency k, is then given by S_k/S_i.

Our specification of invoicing in a basket currency provides us with a general approach that encompasses several standard particular cases. For instance, the case of "producer currency pricing" (PCP), under which exchange rate fluctuations are fully passed-through to the consumer, corresponds to $\gamma_i^{j,\,\text{cur}\,j} = 1$. The case of "local currency pricing" (LCP), under which consumer prices are insulated from exchange rate movements, corresponds to $\gamma_i^{j,\,\text{cur}\,i} = 1$. Pricing in a "vehicle currency" (VCP) corresponds to $\gamma_i^{j,\,\text{cur}\,j} = \gamma_i^{j,\,\text{cur}\,i} = 0$.

For brevity, we consider five corner cases of invoicing, as illustrated by Figure 1. For each case the arrows represent the trade flows between the various countries along with the invoicing currency (for instance a label C

[8] Corsetti and Pesenti (2002) analyze the interaction between policy rules and the invoicing decisions while assuming constant returns to scale. While they show the possibility of multiple equilibria, the only stable has firms setting their prices fully in their own currency.

on the arrow from country C to country A indicates that exports from C to A are invoiced in the currency of country C). We refer to the first two cases as symmetric cases, as there is either full exchange rate pass-through (PCP-SYM case) or no exchange rate pass-through (LCP-SYM case) for all trade flows. We do not focus on these cases are they are the standard ones in the literature.

The next two cases capture the first dimension of the international role of the center currency A, namely its use as the invoicing currency for all trade flows that involve the center. The two cases differ by the extent to which intra-periphery trade is invoiced in the producer or consumer currency, with either full pass-through (DOL-PCP case) or no pass-through (DOL-LCP case). The final case (DOL-DOL) captures the second dimension of the international role of the center currency A, as trade flows within the periphery are also invoiced in that currency. A central feature of that case is the impact of exchange rate fluctuations between currency A and periphery currencies on the price of intra-periphery imports relative to local goods in the periphery. Our analyzes focuses on the last three cases, with particular emphasis on DOL-DOL.

3.5 Technology and output

Firms use a simple technology with constant returns to scale over labor hours worked in production of good z, $H_i(z)$:

$$Y_i(z) = K_i H_i(z) \qquad i = A, B, C \tag{9}$$

The country-wide productivity terms K_i are subject to random shocks, and firms set their prices before the realization of these shocks. For simplicity, we adopt the standard assumption that productivity shocks are log-normal, with mean zero. The demands faced by the various firms are computed by aggregating across the various agents the derived allocation of consumption. Using the pricing structure detailed above, the output of a firm producing brand z in country A is equated to demand by consumers in A,B, and C

$$\begin{aligned} Y_A(z) \;=\; & \alpha \left[\tilde{P}_A^A(z)\right]^{-\lambda} \left(P_A^A\right)^{\lambda-1} P_A C_A \\ & + \frac{1-\alpha}{2} \left[\tilde{P}_B^A(z) \left(S_B\right)^{\gamma_B^{i,\text{ cur } B}-1} \left(S_C\right)^{\gamma_B^{A,\text{ cur } C}}\right]^{-\lambda} \left(P_B^A\right)^{\lambda-1} P_B C_B \\ & + \frac{1-\alpha}{2} \left[\tilde{P}_C^A(z) \left(S_B\right)^{\gamma_C^{A,\text{ cur } B}} \left(S_C\right)^{\gamma_C^{i,\text{ cur } C}-1}\right]^{-\lambda} \left(P_C^A\right)^{\lambda-1} P_C C_C \end{aligned} \tag{10}$$

The demands faced by firms in country B and C are computed similarly. In equilibrium all firms in a given country are identical. We can then drop the

z index and write (10) in terms of per-capita output:

$$Y_A = \alpha \frac{P_A C_A}{P_A^A} + \frac{1-\alpha}{2}\left[\frac{P_B C_B}{P_B^A} + \frac{P_C C_C}{P_C^A}\right] \tag{11}$$

3.6 Exchange rates

We abstract from government spending and assume that the seigniorage income from monetary creation is repaid to the domestic households as lump sum income. Regardless of the structure of invoicing, the exchange rates are:

$$S_B = \frac{M_A}{M_B} \quad ; \quad S_C = \frac{M_A}{M_C} \tag{12}$$

(12) shows that exchange rates are fully determined by the relative monetary stances, a feature that is common to the various contributions in the literature. [9]

3.7 The flexible price allocation

A useful benchmark is given by the situation where goods prices are fully flexible. If firms can adjust their prices following the realization of shocks and the response by monetary authorities, prices are a constant markup over marginal cost (wage adjusted for productivity). Using the labor supply (7), the price set by a firm in country j for sales to country i in terms of country j currency is expressed as:

$$P_i^j = \frac{\lambda\kappa}{\lambda - 1}\frac{1}{\chi}\frac{M_j}{K_j} \tag{13}$$

(13) shows that the law of one price holds, as a given good sells for the same price in any country. This price reflects the ratio between the monetary stance in country j and productivity.

The ability of firms to reset prices implies that productivity shocks are fully transmitted to output, with no impact on hours worked. Consumptions are driven by weighted averages of productivity shocks, with the weights corresponding to the shares of the various goods in the consumption baskets (1)-(2). Abstracting from the direct impact of real balances on utility, the utility (5) is the same in all three countries and reflects structural parameters:

$$U_{i,\text{flexible prices}} = E\left[\ln\left(C_i\right) - \kappa H_i\right] = \Phi \tag{14}$$

where $\Phi = \ln\left(\frac{\lambda-1}{\lambda\kappa}\right) - \frac{\lambda-1}{\lambda}$.

[9] A shortcoming of this result is that the model implies a volatility of exchange rate well below the one observed in the data . This does not alter the focus of the paper, and can be addressed by the inclusion of shocks to the money demand. Such shocks add complexity to our solutions but do not alter our resulting conclusions.

3.8 Optimal price setting

When prices have to be set in advance, a firm in country j sets its prices in order to maximize the expected discounted value of its profits. As all firms are domestically owned, the discount factor is the marginal utility of income in country j. Using the pass-through structure (8), the labor supply (7) and the solution for the exchange rate (12), the home country price set by a firm in country j for sales to country i is written as:

$$\tilde{P}_i^j = \frac{\lambda\kappa}{\lambda-1}\frac{1}{\chi}E\left(\frac{1}{K_j}\left(M_A\right)^{\gamma_i^{j,\text{ cur }A}}\left(M_B\right)^{\gamma_i^{j,\text{ cur }B}}\left(M_C\right)^{\gamma_i^{j\text{ cur }C}}\right) \tag{15}$$

The optimal preset price (15) is conceptually similar to the optimal flexible price (13). Prices are again set as a markup over marginal cost, which is a ratio between monetary stances and the productivity of the firm. (15) shows that the expected marginal cost is relevant, as opposed to its realized value in (13). In addition, the marginal cost in (15) reflects a weighted average of the monetary stances in all countries, reflecting their role in the invoicing of trade, while only the domestic monetary stance matters in (13). The later point of course does not apply to domestic sales which are fully invoiced in the domestic currency: $\gamma_j^{j,\text{ cur }j} = 1$, $\gamma_j^{j,\text{ cur }k\neq j} = 0$.

4 The design of monetary policy

4.1 The prominent role of the center

Before computing the ex-ante rule through which monetary policy should respond to shocks, it is useful to compute the ex-post impact of monetary policies of each country on consumption. Using the money demand (7), the consumer price indexes (3)-(4), the pass-through structure (8) and the solution for the exchange rate (12), consumption in country i takes the following form:

$$C_i = \Theta_i\left(M_A\right)^{\xi_A^i}\left(M_B\right)^{\xi_B^i}\left(M_C\right)^{\xi_C^i} \tag{16}$$

where the ξ^i's are coefficients that reflect the pattern of invoicing and the term Θ_i reflects the preset components of prices, $\tilde{P}_i^j$, in (8).[10] While Θ_i is not affected *ex-post* by the realization of shocks and monetary stances, it does reflect the impact of *ex-ante* policy rules on the level at which the forward looking-prices are set (15). (16) shows that productivity shocks have no direct ex-post impact on consumption, a standard result in models with preset prices.

[10] The exact values of the various ξ^i's and Θ_i can be found in the technical appendix.

The impact of monetary policy (the ξ^i's) reflects the extent to which consumer prices in country i are invoiced in currency j: if no prices are invoiced in currency j, then consumption in country i is fully insulated from movements in the monetary stance in country j.[11] A direct implication is that a currency with an international role has a relatively large impact on consumption across the world. We illustrate this point by considering a worldwide measure of consumption, computed as a weighted average of consumptions with the weights reflecting the size of the various countries:

$$C_W = (C_A)^{0.5} (C_B C_C)^{0.25}$$

Aggregate measures of Θ_W and M_W are constructed along similar lines.

Result 1 *In the presence of an international role for the center currency, the center's monetary policy has an impact on worldwide consumption that exceeds the size of the center country. This aspect is more marked when the international role extends to the second dimension of intra-periphery trade.*

Under the symmetric cases, the worldwide impact of the monetary stance in each country simply reflects its size: $C_W = \Theta_W M_W$. In the presence of an international role for currency A, its monetary policy has a disproportionately large impact, especially when its currency is used in the invoicing of intra-periphery trade (the second dimension). Conversely, monetary policy in the periphery countries have a relatively small impact:

$$\begin{aligned} C_W^{\text{First dimension}} &= \Theta_W M_W \left[\frac{M_A}{(M_B)^{0.5} (M_C)^{0.5}} \right]^{\frac{1-\alpha}{2}} \\ C_W^{\text{Second dimension}} &= \Theta_W M_W \left[\frac{M_A}{(M_B)^{0.5} (M_C)^{0.5}} \right]^{\frac{2-\alpha}{4}} \end{aligned}$$

Intuitively, a monetary expansion in country A depreciates its currency, as shown by (12). Under the first dimension of the international role, this boosts its exports to the periphery, with no offsetting contraction of its imports. Under the second dimension of the international role, the depreciation lowers the price paid by the consumer in a periphery country for goods produced in the other periphery country, leading to a boost in intra-periphery trade.

[11] For instance, we can show that the coefficients for consumption in country B are:

$$\begin{aligned} \xi_A^B &= (1-\alpha)\, \gamma_B^{A,\text{ cur } A} + \frac{\alpha}{2} \gamma_B^{C,\text{ cur } A} \\ \xi_B^B &= \frac{\alpha}{2} + (1-\alpha)\, \gamma_B^{A,\text{ cur } B} + \frac{\alpha}{2} \gamma_B^{C,\text{ cur } B} \\ \xi_C^B &= (1-\alpha)\, \gamma_B^{A,\text{ cur } C} + \frac{\alpha}{2} \gamma_B^{C\text{ cur } C} \end{aligned}$$

While the relatively large impact of the center monetary stance relies on trade flows between the center and the periphery under the first dimension, this is not the case under the second dimension. Even if the center and the periphery are completely disconnected ($\alpha = 1$), the impact through intra-periphery trade remains. Result 1 is illustrated in Figure 2 which shows the impact of a 1 percent increase in M_A on worldwide consumption, C_W, depending on the degree of integration, α. The impact simply reflects the size of country A under the symmetric cases. The impact is larger when there is an international role, especially when it extends to the second dimension.

4.2 Impact of monetary policy stance

The goal of monetary policy is to maximize some combination of the welfare of the representative agents in the various countries, given by (5). We take the standard approach of ignoring the small direct impact of real balances on welfare and focusing on consumption and hours:

$$U_i = E \ln (C_i) - \kappa E H_i \tag{17}$$

Under our specification, expected hours worked boil down to a simple function of the structural parameters of the economy, regardless of the structure of invoicing, a well-known feature of such models (Corsetti and Pesenti 2005a): $\kappa E H_i = (\lambda - 1)/\lambda$. The welfare (17) can then be assessed by focusing on the consumption component. The welfare of agent in country i is given by taking the expected value of the log of (16), and explicitly writing the preset prices in Θ_i by using the optimal pricing rule (15). The key element is that the preset prices are affected by the expected monetary stances, as shown by (15).

The first step towards setting the optimal monetary stance is to compute the marginal impact of monetary policy in a given state of nature s on the expected log of consumption. The resulting derivatives can be expressed in terms of log-linear approximations around a steady state where productivity is constant. Denoting such log deviations by San-Serif variables, the marginal impact of monetary stance in country A in state s on the expected log consumption in country A is written as:

$$\begin{aligned}
&\frac{\partial E \ln (C_A)}{\partial M_{A,s}} \\
= \;& -\alpha \pi_s \left(\mathsf{m}_{A,s} - \mathsf{k}_{A,s} \right) \\
& -\pi_s \frac{1-\alpha}{2} \gamma_A^{B,\text{ cur } A} \left[\begin{array}{c} \gamma_A^{B,\text{ cur } A} \mathsf{m}_{A,s} + \gamma_A^{B,\text{ cur } B} \mathsf{m}_{B,s} \\ + \gamma_A^{B,\text{ cur } C} \mathsf{m}_{C,s} - \mathsf{k}_{B,s} \end{array} \right] \\
& -\pi_s \frac{1-\alpha}{2} \gamma_A^{C,\text{ cur } A} \left[\begin{array}{c} \gamma_A^{C,\text{ cur } A} \mathsf{m}_{A,s} + \gamma_A^{C\text{ cur } B} \mathsf{m}_{B,s} \\ + \gamma_A^{C\text{ cur } C} \mathsf{m}_{C,s} - \mathsf{k}_{C,s} \end{array} \right]
\end{aligned} \tag{18}$$

where π_s is the probability of state s being realized. Similar expressions can be derived for the marginal impact of the monetary stance in any country on the expected log consumption in any country.

Intuitively, (18) reflects the forward looking pricing of firms (15). Consider the first term on the right-hand side of (18). If in state s the monetary stance in country A expands beyond productivity ($\mathsf{m}_{A,s} > \mathsf{k}_{A,s}$), the wage paid by firms rises beyond productivity and they face a higher marginal cost. This induces them to charge a high price ex-ante, with the magnitude reflecting the probability that state s occurs. A high preset price then reduces consumption in all states of the world, especially when domestic goods account for a large share of the consumption basket, explaining the negative impact of $\mathsf{m}_{A,s} - \mathsf{k}_{A,s}$ in (18). The last two terms on the right-hand side of (18) reflect a similar aspect for imported goods, for which the expected marginal cost reflects the various world currencies, to the extent that they are used in invoicing the goods imported by country A.

The optimal monetary policy is computed by setting some combination of the marginal impacts similar to (18) to zero, with different objectives translating into different combinations as detailed below. We refer to the resulting log linear relation between the monetary stance and the various shocks as a *policy rule*. Our analysis focuses on the design of optimal policy rules and we abstract from the issue of discretionary policy. Under our assumption of lognormality for the various shocks, the expected log deviations are zero ($E\mathsf{k}_i = 0$) and the linear rule implies a similar result for the monetary stances ($E\mathsf{m}_i = 0$).

Using the forward looking prices (15), the welfare in the various countries can be written in terms of the variances of the monetary stances and shocks, as well as the invoicing structure. For instance, the welfare in country A is:

$$\begin{aligned}\hat{U}_A \;=\; & -\alpha\frac{1}{2}Var\left[\mathsf{m}_A - \mathsf{k}_A\right] \\ & -\frac{1-\alpha}{2}\frac{1}{2}Var\left[\gamma_A^{B,\text{ cur }A}\mathsf{m}_A + \gamma_A^{B,\text{ cur }B}\mathsf{m}_B + \gamma_A^{B,\text{ cur }C}\mathsf{m}_C - \mathsf{k}_B\right] \\ & -\frac{1-\alpha}{2}\frac{1}{2}Var\left[\gamma_A^{C,\text{ cur }A}\mathsf{m}_A + \gamma_A^{C\text{ cur }B}\mathsf{m}_B + \gamma_A^{C\text{ cur }C}\mathsf{m}_C - \mathsf{k}_C\right]\end{aligned} \tag{19}$$

where Var denotes the variance. $\hat{U}_A$ is expressed relative to the welfare under flexible prices (14), with $\hat{U}_A = 0$ indicating that the welfare under preset prices corresponds to the level under flexible prices. (14) shows that the best potential outcome for monetary policy is to set all variance to zero and brings the economy to the allocation that prevails under flexible prices.

The similarity of the various terms in (18) and (19) highlights the role of policy rule in the determination of forward-looking prices. Consider the first term on the right-hand side of (19). If the monetary stance in country

A does not move in line with productivity in various states ($\mathsf{m}_{A,s} \neq \mathsf{k}_{A,s}$), firms face volatile marginal cost as wages sometimes differ from productivity ($Var\left[\mathsf{m}_A - \mathsf{k}_A\right] > 0$). This induces them to charge a higher price ex-ante, thereby reducing consumption in all states, and lowering welfare. A similar interpretation applies to the last two terms on the right-hand side of (19) which capture the volatility of marginal costs for foreign firms selling goods in country A, with the weights on the various monetary stances reflecting the invoicing structure. The welfare level under specific monetary policy rules is computed by substituting the rules into (19).

4.3 Optimal monetary policy in a decentralized setting

4.3.1 Monetary rules

We first consider a decentralized Nash equilibrium where each monetary authority focuses on maximizing the welfare of its own residents only, and ignores any impact on the welfare of residents in other countries. The policy stances in state s are then set to satisfy the following first-order conditions:

$$\frac{\partial E \ln\left(C_A\right)}{\pi_s \partial M_{A,s}} = \frac{\partial E \ln\left(C_B\right)}{\pi_s \partial M_{B,s}} = \frac{\partial E \ln\left(C_C\right)}{\pi_s \partial M_{C,s}} = 0$$

This gives a linear system of three equations in three unknowns, $\mathsf{m}_{i,s}$ for $i = A, B, C$ and three exogenous productivity shocks. For convenience, we define the following periphery-wide measure of shocks:

$$\mathsf{k}_{P,s} = \left(\mathsf{k}_{B,s} + \mathsf{k}_{C,s}\right)/2$$

Result 2 *In the symmetric cases, decentralized monetary policy offsets domestic shocks when there is full exchange rate pass-through, and offsets a combination of worldwide shocks that reflect the composition of the local consumption basket when there is no pass-through.*

This result is standard in the literature. Under complete exchange rate pass-through, the monetary authority in a country can only stabilize the marginal cost of its own producers, and has no influence on the costs of foreign firms selling in the country. The optimal policy then fully stabilizes the marginal cost of domestic firms ($\mathsf{m}_{i,s} = \mathsf{k}_{i,s}$, $i = A,\ B,\ C$). When import prices are fully insulated from exchange rate movements, the monetary authority affects the volatility of marginal cost of foreign firms selling in the country. The optimal policy then reflect a trade-off between stabilizing the cost of domestic and foreign producers who sells in the country:

$$\mathsf{m}_{A,s} = \alpha \mathsf{k}_{A,s} + (1-\alpha)\,\mathsf{k}_{P,s} \quad , \quad \mathsf{m}_{B,s} = \mathsf{m}_{C,s} = (1-\alpha)\,\mathsf{k}_{A,s} + \alpha \mathsf{k}_{P,s}$$

Result 3 *In the presence of an international role of the center currency, the center's monetary policy targets a combination of worldwide shocks which reflect the composition of the consumption basket of the center.*

The international role of currency A implies that all goods sold in the country are invoiced in currency A, whether or not the international role extends to the second dimension. All the terms in (19) then reflect the monetary stance in the center m_A. Monetary policy then trades-off the stabilization of marginal costs of domestic firms, $Var\left[\mathsf{m}_A - \mathsf{k}_A\right]$, versus foreign firms $Var\left[\mathsf{m}_A - \mathsf{k}_B\right]$ and $Var\left[\mathsf{m}_A - \mathsf{k}_C\right]$:

$$\mathsf{m}_{A,s} = \alpha \mathsf{k}_{A,s} + (1-\alpha)\,\mathsf{k}_{P,s} \tag{20}$$

Result 4 *Under the first dimension of the international role of the center currency, monetary policy in the periphery depends on the extent of intra-periphery pass-through. Periphery policy fully targets domestic shocks under complete pass-through, and targets the periphery-wide average of shocks in the absence of pass-through.*

When intra-periphery trade flows are fully affected by exchange rate movements, the optimal policy fully stabilizes the marginal cost of domestic firms: $\mathsf{m}_{i,s} = \mathsf{k}_{i,s}$, $i = B, C$. Intuitively, the monetary authorities cannot affect the marginal cost of firms in the center or in the other periphery country, as they reflect solely the local monetary stances. Their only impact is on the marginal cost of domestic firms, on which they focus. The situation is different when import prices from the other periphery country are insulated from exchange rate movements. While the monetary authority still has no impact on the marginal cost of firms in the center, it affects the costs of firms in the other periphery country. The optimal policy then trades-off the stabilization of marginal cost in the two periphery countries: $\mathsf{m}_{i,s} = \mathsf{k}_{P,s}$, $i = B, C$.

Result 5 *In the presence of an international role of the center currency, monetary policy in any periphery country focuses solely on domestic shocks.*

When all import prices are invoiced in the center currency, the monetary authority in a periphery country has no impact on the marginal cost of foreign firms. It only affects the cost of domestic firms, and fully focuses on stabilizing them: $\mathsf{m}_{i,s} = \mathsf{k}_{i,s}$, $i = B, C$.

Our analysis stresses the asymmetric form of monetary policy rules between the center and the periphery in the presence of an international role for the center's currency, an aspect indicated by Corsetti and Pesenti (2005a,b) and Devereux, Shi, and Xu (2006) who focus on the first dimension of the international role.

The various policy rules can be concisely illustrated through the volatility of exchange rates. For brevity, we focus on the case where the shocks are perfectly correlated across the periphery countries ($\mathsf{k}_C = \mathsf{k}_B$).

Result 6 *In the presence of an international role of the center currency, the volatility of the exchange rate falls in between the extremes of the symmetric cases with and without pass-through, regardless of whether the international role includes the second dimension or not.*

In the symmetric cases, the exchange rate moves is line with the relative productivity shocks in the center and the periphery when there is full exchange rate pass-through. It fluctuates much less in the absence of pass-through:

$$\begin{aligned} Var\left(\mathsf{s}_B\right)_{\text{PCP-SYM}} &= Var\left[\mathsf{k}_A - \mathsf{k}_B\right] \\ Var\left(\mathsf{s}_B\right)_{\text{LCP-SYM}} &= \left(2\alpha - 1\right)^2 Var\left[\mathsf{k}_A - \mathsf{k}_B\right] \end{aligned}$$

In the presence of an international role for currency A, the volatility of the exchange rate falls in between the two extremes ($2\alpha - 1 < \alpha < 1$):

$$Var\left(\mathsf{s}_B\right)_{\text{DOL}} = \alpha^2 Var\left[\mathsf{k}_A - \mathsf{k}_B\right]$$

Intuitively, the volatility of the exchange rate reflects its ability to alter relative prices. This ability is at its highest when all trade flows are characterized by complete pass-through, leading policy makers to extensively rely on the exchange rate to deliver optimal relative prices. When the exchange rate has no impact on any import prices, its usefulness is limited and policy makers do not engineer large variations. In the presence of an international role for the center currency, the situation is in between the symmetric extremes. While exchange rate movements do not affect relative prices in the center, they do affect relative prices in the periphery with a depreciation of the center currency reducing the cost of center goods.

4.3.2 Welfare

A striking result of our analysis so far is that the monetary policy rules are little affected by the second dimension of the international role of the center currency. Indeed, when periphery shocks are perfectly correlated ($\mathsf{k}_C = \mathsf{k}_B$), the optimal policy for a periphery country is always to focus on domestic shocks, whether or not the international role of the center currency encompasses the second dimension. The point is even more striking for the center since its optimal monetary policy rule is never affected by the use of the center currency in intra-periphery trade. While one may infer that the second dimension is not an interesting aspect of international interdependence, this inference is inaccurate for two reasons. First, monetary policy rules

are affected by the second dimension when we consider a cooperative policy outcome, as shown below. Second, the same rules have very different implications for welfare depending on whether the extent of international role of the center currency, an aspect to which we now turn.

As the symmetric cases have already been analyzed by existing contributions, we briefly remind the reader of their characteristics. When exchange rate pass-through is complete, monetary policy is able to fully replicate the flexible price outcome as exchange rate movements generate efficient adjustments in relative prices. This is not the case in the absence of pass-through, where the rigidity of prices reduces welfare.

Focusing on case with an international role for the center currency, the welfare depends on the volatility of relative shocks between the center and the periphery, $Var\left[\mathsf{k}_A - \mathsf{k}_P\right]$, as well as between the periphery countries, $Var\left[\mathsf{k}_B - \mathsf{k}_C\right]$.

Result 7 *In the presence of an international role of the center currency, welfare in the center is reduced, whether the role includes the second dimension or not.*

The welfare cost for the center reflects the fact that relative prices are fully insulated from exchange rate movements, and cannot efficiently adjust to reflect productivity differentials, both between the center and the periphery and between periphery countries:

$$\hat{U}_A = -\frac{\alpha\left(1-\alpha\right)}{2} Var\left[\mathsf{k}_A - \mathsf{k}_P\right] - \frac{1-\alpha}{8} Var\left[\mathsf{k}_B - \mathsf{k}_C\right]$$

Result 8 *Under the first dimension of the international role of the center currency, welfare is equalized across the periphery countries. Welfare is adversely affected by the volatility of relative center-periphery shocks due to the fact that the center monetary authority does not take account of its impact on prices in the periphery. In addition, relative intra-periphery shocks are costly in the absence of intra-periphery pass-through.*

Welfare for both periphery countries is only affected by the volatility of relative productivity shocks, and not by the volatility of absolute shocks:

$$\begin{aligned}
\left(\hat{U}_i\right)_{\text{DOL-PCP}} &= -\frac{\left(1-\alpha\right)^3}{2} Var\left[\mathsf{k}_A - \mathsf{k}_P\right] \qquad\qquad i = B, C \\
\left(\hat{U}_i\right)_{\text{DOL-LCP}} &= -\frac{\left(1-\alpha\right)^3}{2} Var\left[\mathsf{k}_A - \mathsf{k}_P\right] - \frac{\alpha}{8} Var\left[\mathsf{k}_B - \mathsf{k}_C\right]
\end{aligned}$$

The adverse impact of relative shocks between the center and the periphery reflects the monetary rule in the center. In the presence of an international

role for the center currency, the monetary authorities in the center do not fully offset domestic shocks (20). A productivity boom in the center is then only accompanied by a moderate depreciation of the currency. While that depreciation has an efficient impact on the periphery by lowering the cost of goods made in the center, this impact remains inefficiently low as the center monetary authority ignores intra-periphery consequences.

In addition, movements in the intra-periphery productivity differential are costly in the absence of pass-through, as relative prices then cannot adjust to switch demand towards the more productive country. No such cost occurs under full pass-through, as relative prices then adjust in an efficient way.

Result 9 *Under the second dimension of the international role of the center currency, movements in the center-periphery welfare differential entail an additional welfare cost. When a periphery country faces more volatile domestic shocks, its welfare is increased relative to the other periphery country.*

The welfare for the two periphery countries are:

$$\begin{aligned}\left(\hat{U}_B\right)_{\text{DOL-DOL}} &= \left(\hat{U}_P\right)_{\text{DOL-DOL}} - \frac{\alpha^2}{4} Covar\left[\mathsf{k}_A - \mathsf{k}_P\right]\left[\mathsf{k}_B - \mathsf{k}_C\right] \\ \left(\hat{U}_C\right)_{\text{DOL-DOL}} &= \left(\hat{U}_P\right)_{\text{DOL-DOL}} + \frac{\alpha^2}{4} Covar\left[\mathsf{k}_A - \mathsf{k}_P\right]\left[\mathsf{k}_B - \mathsf{k}_C\right]\end{aligned}$$

where:

$$\left(\hat{U}_P\right)_{\text{DOL-DOL}} = -\left[\frac{(1-\alpha)^3}{2} + \frac{\alpha^3}{4}\right] Var\left[\mathsf{k}_A - \mathsf{k}_P\right] - \frac{\alpha}{16} Var\left[\mathsf{k}_B - \mathsf{k}_C\right]$$

Relative shocks between the center and the periphery are more costly under the second dimension because they lead to inefficient movements in intra-periphery relative prices. Following an increase in productivity in the center, the monetary authority there follows an expansionary policy which depreciates the center's currency. This reduces the prices of intra-periphery imports in the periphery, which is inefficient as there has been no change in productivity within the periphery. Movements the intra-periphery productivity differential also entail a cost, as relative prices cannot efficiently respond because import prices are set in the center currency.

Assuming that the shocks in the center and the periphery are not correlated, the welfare is higher in the periphery country with the most volatile shocks:

$$\left(\hat{U}_B\right)_{\text{DOL-DOL}} - \left(\hat{U}_C\right)_{\text{DOL-DOL}} = \frac{\alpha^2}{4}\left(Var\left[\mathsf{k}_B\right] - Var\left[\mathsf{k}_C\right]\right)$$

How can a country be better off when it faces more volatile shocks? This surprising result reflects the fact that under the second dimension, monetary

policy in the periphery is better suited at offsetting domestic shocks than foreign ones. For clarity, consider the case where productivity is volatile in country B but not in country C. This volatility directly feeds into the marginal cost and prices of firms located in country B. This adverse effect can however be offset for country B, but not for country C. Specifically, the impact on consumer prices in country B is through the price of domestic goods, which is proportional to $Var\left[\mathsf{m}_B - \mathsf{k}_B\right]$. The monetary authority in country B can then use policy to limit the impact of the volatile shocks on the marginal cost of its producers. No such recourse is available for country C where the cost of goods imported from country B reflects $Var\left[\mathsf{m}_A - \mathsf{k}_B\right]$, due to the fact that these goods are invoiced in the center currency. This problem does not emerge when the international role is limited to the first dimension, as the authorities in country C can either directly stabilize the cost (in the DOL-LCP case) or also benefit from the stabilization effort of the monetary authority in country B (in the DOL-PCP case).

Our analysis shows that while the second dimension of the international role of the center currency has a limited impact on the conduct of monetary policy in a decentralized setting, it substantially affects the welfare in the various countries. Our results are illustrated by means of a simple example that focuses on the cases with an international role for the center currency and emphasizes the impact of the degree of center-periphery integration α. We first focus on the role of productivity differentials between the center and the periphery by assuming that productivity shocks in country B and country C are perfectly correlated and equally volatile, but are independent from shocks in the center. We set the standard deviation of productivity shocks at 5% for all countries, leading to a standard deviation for the center-periphery productivity differential of 7%.

The welfare levels under a decentralized policy are presented in Figure 3, where the dotted line shows the welfare for the center. When the international role of the center currency is limited to the first dimension, the welfare is higher in the periphery countries (dashed lines) than in the center. This reflects the fact that exchange rate movements lead to fluctuations in relative prices in the periphery that are partially efficient. Introducing the second dimension reduces the welfare in the periphery (solid line), as fluctuations in the value of the center currency now lead to inefficient movements in import prices in the periphery. When the center and the periphery are not tightly connected (α is high), the adverse impact of center-periphery exchange rate movements on the intra-periphery relative prices dominate their benefit on the center-periphery relative prices, making the periphery countries worse off.

We next assess the impact of asymmetric shocks in the periphery. We still assume that shocks are perfectly correlated across periphery countries, but

take them to be twice as volatile in country B as in country C. Specifically, we set the standard deviation of shocks in country B and C at 6.6% and 3.3% respectively. With the standard deviation of shocks in the center kept at 5%, this ensures that the standard deviation of the center-periphery productivity differential remains at 7%, while the standard deviation of the intra-periphery productivity differential, $\mathsf{k}_B - \mathsf{k}_C$, is equal to 3.3%.

The welfare under a decentralized monetary policy is shown in Figure 4, with panels A and B focusing on the first and second dimension of the international role, respectively. Under the first dimension, there is no welfare gap between the periphery countries, and the volatility of the intra-periphery productivity differential lowers the welfare in the absence of intra-periphery pass-through. A welfare gap emerges under the second dimension (panel B) in favor of the volatile periphery country. This gap is larger when the center and the periphery are not tightly connected, as imports from the rest of the periphery then account for a larger share of the consumption basket in a periphery country.

4.4 Optimal monetary policy in a cooperative setting

4.4.1 Monetary rules

Our analysis shows that the monetary policy of the center has a substantial impact on the periphery as it leads to partially efficient movements in center-periphery relative prices, and inefficient ones for intra-periphery relative prices. While sizable, these aspects are ignored by the monetary authority in the center as they do not impact the welfare of the center. The presence of this externality points to a benefit, in our setting, from cooperation in the conduct of monetary policy.

Consider a global cooperation setup in which monetary authorities in any country choose their rule to maximize the weighted average of the welfare of various consumers:

$$0 = \frac{\partial E \ln\left(C_A\right) + \frac{1}{2}\partial E\left[\ln\left(C_B\right) + \ln\left(C_C\right)\right]}{\partial M_{i,s}} \qquad i = A,\, B,\, C$$

As in the decentralized setup, this gives a linear system of three equations in three unknowns, $\mathsf{m}_{i,s}$ for $i = A, B, C$ and three exogenous productivity shocks.[12] We again focus on the cases with an international role for the center currency, as there are no gain from cooperation in the symmetric cases, as shown by Corsetti and Pesenti (2005a).

[12] As the externality is linked to the monetary policy of the center, cooperation can be beneficial only if it involves the center. We can show that a cooperation limited to the periphery countries leads to the same policy rules and welfare as under the decentralized poilicy.

Result 10 *The monetary policy rules for the periphery countries are not affected by a cooperative monetary policy setting.*

Whether policy is conducted in a decentralized or cooperative setting, the monetary rules for the periphery countries are the same as derived above. Intuitively, this reflects the absence of externalities in the decentralized setting, as the monetary authority in a periphery country sets its policy by taking full account of its impact on all prices.[13]

Result 11 *Under the first dimension of the international role of the center currency, cooperation calls for monetary policy in the center to be more inward-looking than under a decentralized setting.*

The monetary rule in the center under the first dimension is given by:

$$\mathsf{m}_{A,s} = \frac{1}{2-\alpha}\mathsf{k}_{A,s} + \left(1 - \frac{1}{2-\alpha}\right)\mathsf{k}_{P,s} \tag{21}$$

Contrasting (20) and (21) shows that the monetary authorities in the center are more inward-looking under the cooperative setting, with their own shocks receiving a larger weight in the policy rule:

$$\frac{1}{2-\alpha} > \alpha$$

Intuitively, a monetary expansion in the center following a center productivity improvement leads to a depreciation of the center's currency against both periphery currencies, lowering import prices in the periphery. This efficient response is ignored by the center monetary authorities in the decentralized setting, but taken into account in the cooperative setting.

Result 12 *Under the second dimension of the international role of the center currency, cooperation calls for monetary policy in the center to be more inward looking only when the center and the periphery are closely linked. In addition, the center monetary policy is less inward looking than under the first dimension alone.*

The monetary policy of the center is:

$$\mathsf{m}_{A,s} = \frac{2}{4-\alpha}\mathsf{k}_{A,s} + \left(1 - \frac{2}{4-\alpha}\right)\mathsf{k}_{P,s} \tag{22}$$

Comparing (21)-(22) shows that, under a cooperative setting, the second dimension reduces the sensitivity of the center monetary policy to its own shocks:

$$\frac{2}{4-\alpha} < \frac{1}{2-\alpha}$$

[13] More specifically, even when it ignores its impact on some prices, as in the DOL-PCP case, this does not distrot its policy choice.

Intuitively, movements in the exchange rate between the center and the periphery countries now have an inefficient impact on the intra-periphery relative prices. Limiting this costs requires a lower response of the center monetary policy to its own shock, relative to the cooperative policy when only the first dimension is present.

Comparing the decentralized (20) and cooperative (22) policies under the second dimension highlights a trade-off. The monetary policy of the center impacts the periphery through two channels that the center ignores in the decentralized setting. Consider a productivity improvement in the center, leading to a monetary expansion there and a depreciation of the center currency. First, this depreciation has a beneficial impact along the center-periphery dimension, as it leads to an efficient reduction in the price of center goods sold in the periphery. Taking this channel into account calls for a larger depreciation, i.e. a more inward-looking policy in the center. Second, the depreciation has a detrimental impact along the intra-periphery dimension, as it generates inefficient movements in the relative prices of periphery goods. Taking this second aspect into account requires a smaller depreciation. The center's policy under cooperation entails a trade-off between these two aspects. The first aspect dominates if the center and the periphery are closely linked (α is low). Specifically, cooperation calls for larger exchange rate movements under the second dimension if:

$$\frac{2}{4-\alpha} > \alpha \Leftrightarrow \alpha < 0.59$$

4.4.2 Welfare

In the presence of an international role for the center currency, the welfare of the periphery is higher under the cooperative setting, a gain that is partially offset by a cost for the center. For clarity, we present the welfare results in terms of the gain compared to the decentralized setting.

Result 13 *Under the first dimension of the international role of the center currency, the gains from cooperation only reflects the productivity differential between the center and the periphery, and are largest when the center and the periphery are closely connected.*

The gains from cooperation are given by:

$$\left(\hat{U}_A\right)^{\text{Gain}}_{\text{First dimension}} = -\frac{(1-\alpha)^4}{2}\left(\frac{1}{2-\alpha}\right)^2 Var\left[\mathsf{k}_A - \mathsf{k}_P\right] < 0 \qquad (23)$$

$$\left(\hat{U}_i\right)^{\text{Gain}}_{\text{First dimension}} = \frac{(1-\alpha)^3}{2}\left[1-\left(\frac{1}{2-\alpha}\right)^2\right] Var\left[\mathsf{k}_A - \mathsf{k}_P\right] > 0 \qquad (24)$$

$$i = B, C$$

(23)-(24) show that when $\alpha = 0.5$ the gain is negative for the center and positive for the periphery, while both are zero when $\alpha = 1$.

Intuitively, the gain from cooperating entirely reflects the impact of the center's policy along the center-periphery dimension. This aspect reflects the extent to which productivity differs between the center and the periphery, and not the extent to which it differs within the periphery. Also, its hinges on the existence of direct trade links between the center and the periphery, and becomes negligible when the two are disconnected.

Result 14 *Under the second dimension of the international role of the center currency, the gains from cooperation are not equalized across the periphery countries. The gains are largest when the center and the periphery are not connected.*

The gains from cooperation are computed as:

$$\left(\hat{U}_A\right)^{\text{Gain}}_{\text{Second dimension}} = -\Phi_A(\alpha)\, Var\left[\mathsf{k}_A - \mathsf{k}_P\right] \tag{25}$$

$$\left(\hat{U}_B\right)^{\text{Gain}}_{\text{Second dimension}} = \Phi_P(\alpha)\, Var\left[\mathsf{k}_A - \mathsf{k}_P\right] - \Omega_P(\alpha)\, Covar\left[\left(\mathsf{k}_A - \mathsf{k}_P\right), \left(\mathsf{k}_B - \mathsf{k}_C\right)\right] \tag{26}$$

$$\left(\hat{U}_C\right)^{\text{Gain}}_{\text{Second dimension}} = \Phi_P(\alpha)\, Var\left[\mathsf{k}_A - \mathsf{k}_P\right] + \Omega_P(\alpha)\, Covar\left[\left(\mathsf{k}_A - \mathsf{k}_P\right), \left(\mathsf{k}_B - \mathsf{k}_C\right)\right] \tag{27}$$

where:

$$\Phi_A(\alpha) = \frac{\alpha}{2}\left(\frac{2-\alpha}{4-\alpha}\right)^2 + \frac{1-\alpha}{2}\left(\frac{2}{4-\alpha}\right)^2 - \frac{\alpha(1-\alpha)}{2}$$

$$\Phi_P(\alpha) = \frac{1-\alpha}{2}\left[(1-\alpha)^2 - \left(\frac{2-\alpha}{4-\alpha}\right)^2\right] + \frac{\alpha}{4}\left[\alpha^2 - \left(\frac{2}{4-\alpha}\right)^2\right]$$

$$\Omega_P(\alpha) = \frac{\alpha}{2}\frac{1}{4-\alpha} - \frac{\alpha^2}{4}$$

The terms $\Phi_A(\alpha)$ and $\Phi_P(\alpha)$ in (25)-(27) are positive for any value of α, implying that cooperation boosts the welfare of the periphery countries, at the expense of the center.

Given the complexity of (25)-(27), the analysis is facilitated by considering the numerical example introduced above. We first focus on the case where productivity shocks in country B and country C are perfectly correlated, with the welfare levels under a decentralized setting illustrated in figure 3. Figure 5 shows the gains and losses from following a cooperative policy, relative to the decentralized policy, with panel A and B focusing on the center and the periphery, respectively. The dotted line show that under the first

dimension the welfare gains and losses are highest when the center and the periphery are closely integrated. The situation under the second dimension is depicted by the solid lines, and two results emerge. First, the magnitudes of the effects are substantially larger than under the first dimension. Second, the gains and losses are highest when the center and the periphery are not integrated. Intuitively, the implications for cooperative policy along the center-periphery and intra-periphery dimensions offset each other when the two regions are closely integrated. When they are disconnected, the main aspect is the inefficient movements in intra-periphery relative prices, which become substantial as intra-periphery imports then account for a large share of the consumption basket of a periphery country.

(26)-(27) show that in general the welfare is not equalized between the two periphery countries. The bracket in the second terms in (26)-(27) can be positive or negative, depending on α. If shocks in the center and the periphery are uncorrelated, (26)-(27) imply:

$$\left(\hat{U}_B\right)^{\text{Gain}}_{\text{Second dimension}} - \left(\hat{U}_C\right)^{\text{Gain}}_{\text{Second dimension}} = \left[\frac{\alpha}{2}\frac{1}{4-\alpha} - \frac{\alpha^2}{4}\right]\left(Var\left[\mathsf{k}_B\right] - Var\left[\mathsf{k}_C\right]\right)$$

The term in bracket is negative when the center and the periphery are loosely integrated (specifically $\alpha > 0.59$), in which case cooperation mostly benefits the periphery country with the least volatile shocks.

Consider for simplicity that productivity fluctuates only in country B,[14] and that the center and periphery fully disconnected ($\alpha = 1$). (20) and (22) then show that the center monetary policy is constant under a decentralized setting, but fluctuates under cooperation. The price of periphery imports in country B is proportional to $Var\left[\mathsf{m}_A - \mathsf{k}_C\right] = Var\left[\mathsf{m}_A\right]$, which increases under cooperation. By contrast, the price of periphery imports in country C is proportional to $Var\left[\mathsf{m}_A - \mathsf{k}_B\right]$, which is reduced under cooperation as the monetary stance in the center then partially offsets the shocks in country B.

The larger gain for the periphery country with the smaller shocks is linked to our earlier finding that this country is worse off in a decentralized setting, relative to the other periphery country. That aspect reflected its inability to influence the volatility of marginal costs of the producers in the volatile periphery country. This problem is reduced under a cooperative setting, as the center monetary stance then offsets shocks in the volatile periphery country to a larger extent.

Our findings can be illustrated to our earlier numerical example. We consider that shocks are more volatile in country B, as assumed for Figure 4. The gains from cooperation are presented in Figure 6. We focus on the gains for the periphery under the second dimension of the international role of the

[14] Specifically, $Var\left[\mathsf{k}_A\right] = Var\left[\mathsf{k}_C\right] = 0$.

center currency, as all other aspects are the same as in Figure 5. Figure 6 clearly shows larger gains for the periphery country with the least volatile shocks, especially when the center-periphery integration is limited.[15]

4.5 Exchange rate peg

The efficiency, or lack thereof, of exchange rate movements is at the core of our analysis. In particular, the large gains from cooperation under the second dimension of the international role of the center currency are driven by the inefficient impact of exchange rate movements between the center and the periphery on the intra-periphery relative prices. A natural question is then whether welfare is increased or reduced when there is an exchange rate peg between the periphery and the center.

Result 15 *Despite the limited efficiency of exchange rate movements, in the context of our model pegging the exchange rate leads to substantial welfare losses.*

First consider the case of decentralized policy. We can show that the center monetary rule is the same whether the periphery countries adopt a peg or their optimal policies.[16] Pegging is then clearly suboptimal as it restricts the policy rule in the periphery and has no effect on the center. A similar conclusion emerges in the cooperative case, assuming that the center sets its policy taking the monetary stances in the periphery as given.

An alternative policy is to allow the center country to be a strategic leader. Specifically, each periphery country pegs its exchange rate to the center. The center monetary authority then sets its policy to maximize the worldwide welfare average, taking into account that its policy is matched by the periphery countries. Such a policy essentially consists of a currency union where monetary policy is delegated to the monetary authority of the center, who takes the union-wide welfare into account when setting its policy. The optimal policy then does not try to alter international relative prices, and simply reacts to the worldwide productivity shock:

$$\mathsf{m}_{i,s} = \mathsf{k}_{W,s} \qquad\qquad i = A,\, B,\, C$$

As this policy entails no exchange rate movements, it leads to welfare levels

[15] The average gain between the two periphery countries correspond to the one in figure 5.

[16] The detailed analysis is presented in an Appendix available on request.

that are independent of the structure of invoicing. Specifically:

$$\begin{aligned}\hat{U}_A &= -\frac{1}{8}Var\left[\mathsf{k}_A - \frac{\mathsf{k}_B + \mathsf{k}_C}{2}\right] - \frac{1-\alpha}{8}Var\left[\mathsf{k}_B - \mathsf{k}_C\right] \\ \hat{U}_i &= -\frac{1}{8}Var\left[\mathsf{k}_A - \frac{\mathsf{k}_B + \mathsf{k}_C}{2}\right] - \frac{\alpha}{8}Var\left[\mathsf{k}_B - \mathsf{k}_C\right] \qquad i = B, C\end{aligned}$$

Figure 7 shows the worldwide welfare under the second dimension of the international role of the center currency, the case where an exchange rate peg is the most likely to have beneficial effects given the cost of exchange rate movements along the intra-periphery dimension.[17] The welfare in the decentralized and cooperative settings are illustrated by the dotted and thin lines, respectively, while the thick line illustrates the welfare under the currency union setting described above. The figure shows that a currency union is the worst of the three cases. It never leads to a more favorable outcome than the decentralized setting, and is substantially worse than the cooperative policy. Of course, these conclusions are from the perspective of our basic macro model of linkages and policy interdependence, which focuses on a particular mechanism and surrounding consequences, without reflecting on the broader arguments for and against choice of exchange rates and choice of invoicing currencies.

5 Conclusion

In this paper, we analyze the impact of the international role of the dollar on macroeconomic interdependence using a simple center-periphery model. We distinguish between two dimensions of the international role of the center currency. In the first, the currency is used in invoicing all trade flows to and from the center. In the second it is used as the invoicing currency for intra-periphery trade flows, an aspect that is empirically relevant and has received little attention in the literature. Under this second dimension, monetary policy in the center country has a substantial impact on the periphery even absent direct trade links. Specifically, a monetary expansion in the center depreciates its currency and makes imported goods cheaper in both periphery countries, boosting intra-periphery trade flows.

We show that the second dimension of the international role of the center currency has sizable implications for the design of monetary policy. A decentralized monetary policy is suboptimal as the monetary authority of the center ignores its impact on intra-periphery transactions. Because of this

[17] We focus on the case where shocks are equally volatile in the two periphery countries, with similar results when the volatility differs.

externality, a cooperative monetary policy can lead to a substantial improvement in periphery welfare. Our analysis also shows that the gains are not evenly spread in the periphery. They are likely to be more pronounced for the periphery country with the least volatile shocks, which was at a disadvantage in a decentralized policy setting. Moreover, we show that despite the limited efficiency of exchange rate movements, a policy of pegging the center-periphery exchange rate is suboptimal from the vantage point of limiting the ability of a country to adjust some dimension of its prices.

Our analysis clearly demonstrates that the international role of a currency is a central feature of international interdependence. While we deliberately maintain a simple theoretical setup for clarity, our analysis can be extended along many directions, First, the assumption of an exogenous structure of invoicing can be relaxed to assess the joint determination of monetary policy and invoicing strategy. Since we do not treat the microfounded motives of invoicing choice in the current paper, our analysis does not assess whether individual producer welfare is higher as a consequence of his invoicing choices, despite the observation that aggregate welfare may be lower along the dimension addressed by our model. Second, the assumption that all trade takes place in final goods can be relexed. Introducing trade in intermediate goods along a production chain spanning several countries is a promising avenue of research. Third, while we assume that price rigidities apply to all goods, in reality, the degree of price stickiness is higher for some goods, such as manufacturing products, than other, such as commodities. If the international role of a currency is concentrated among goods with relatively flexible prices, such as in commodity and raw material pricing, the magnitudes of the effects we document are likely to be reduced. Finally, we focus on the ability of the exchange rate to generate efficient movements in international relative prices. Our finding that a peg is not optimal then abstracts from the extensive range of other motives for having fixed exchange rates.

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