EUROPEAN CENTRAL BANK

EUROSYSTEM

Working Paper Series

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Global value chain participation and exchange rate pass-through

No 2327 / November 2019

Abstract

This paper draws a causal link between the rise of global value chain participation and the decline of exchange rate pass-through to import prices over the last decades. We first present a structural two-country model in order to illustrate how participation in global value chains can impact exchange rate pass-through to import prices. In the model, the sensitivity of an economy's domestic-currency production costs to exchange rate changes rises as it participates more in global value chains by importing a larger share of its intermediate inputs. The increased sensitivity of the economy's domestic-currency production costs to exchange rate changes translates into a higher sensitivity of its domestic-currency export prices. The latter implies a reduction of the sensitivity of the economy's *foreign*-currency export prices — i.e. its trading partner's local-currency import prices — to exchange rate changes. Hence, an increase in the economy's global value chain participation implies a fall in its trading partner's exchange rate pass-through to import prices. We then provide empirical evidence in a cross-country panel dataset for the time period from 1995 to 2014 that is consistent with the mechanisms spelled out in the structural model. In particular, the data suggest that exchange rate pass-though to export prices is higher in economies which participate more in global value chains, and that exchange rate pass-though to import prices is lower in economies whose trading partners participate more in global value chains. Quantitatively, our estimates imply that the rise in global value chain participation can account for about 50% of the decline in exchange rate pass-through to import prices since the mid-1990s.

Keywords: Global value chain participation, exchange rate pass-through.
JEL-Classification: F32, F41, F62.

Non-technical summary

A salient feature of the past decades has been the decline in the pass-through of exchange rate changes to the local-currency price of imported goods. Understanding the drivers of this decline is important as exchange rate pass-through (ERPT) is a key determinant of the international propagation of shocks, with implications for the movements of relative prices, the adjustment of external imbalances, business cycle co-movements and the effectiveness of monetary policy. The degree of ERPT is particularly relevant for central banks with an explicit inflation target. For example, a lower ERPT to import prices in part insulates the domestic economy from foreign monetary policy shocks. At the same time, a lower ERPT to import prices weakens the exchange rate channel of domestic monetary policy.

The literature has put forth several explanations for the secular decline in ERPT to import prices. While some studies relate the lower ERPT to import prices to a declining share of energy goods — which tend to have a higher pass-through — in total imports, other provide evidence for the role of increased competition for variations in ERPT to import prices.

In this paper we consider another possible explanation for the secular decline in ERPT to import prices: The rise of global value chains. Spurred by the decline in transportation costs, the adoption of trade-liberalising policies as well as advances in information and communication technologies, firms increasingly disperse stages of production across countries. By fragmenting production chains internationally, the share of intermediate goods in total trade has risen continuously relative to that of final goods. Data suggest that trade in intermediate goods and services nowadays accounts for 56% and 73% of overall trade flows in goods and services. For a given degree of ERPT to local-currency import prices and a given mark-up, a larger share of imported intermediates in total intermediates used in the production of exports implies a larger ERPT to local-currency *export* prices. In turn, the larger sensitivity of local-currency export prices to exchange rate changes implies a smaller sensitivity of foreign-currency import prices abroad.

For example, assume the euro area imports intermediate goods for the production of its exports from the rest of the world. Moreover, assume that — for the sake of simplicity — changes in the euro area's nominal effective exchange rate transmit fully and instantaneously into euro area local-currency import prices, and that foreign and euro area exporters keep their mark-ups constant. Now suppose the euro depreciates in nominal effective terms. For a given level of ERPT to local-currency import prices in the euro area and given foreign exporters' mark-ups, the depreciation of the euro will increase the local-currency costs of imported intermediates for euro area exporters. Moreover, for a given level of mark-ups euro area exporters will increase their local-currency prices commensurately with the rise in their production costs stemming from the depreciation of the euro and the associated rise of the local-currency costs of imported intermediates. Thus, foreign importers will experience dampened variation of *foreign*-currency import prices of euro area goods in response to variations of the euro's exchange rate.

We first illustrate the mechanism described above in a structural two-country model with trade in intermediate goods. The model predicts that ERPT to export prices rises as the economy's global value chain participation (GVCP) increases. Moreover, the model predicts that due to the increase in ERPT to local-currency export prices in the Home economy stemming from greater GVCP, in the Foreign economy ERPT to local-currency import prices falls.

We then investigate empirically the role of GVCP for the decline in ERPT to import prices. In particular, we first obtain estimates of the ERPT to export prices for 22 advanced economies for the time period from 1995 to 2014, and analyse the role of GVCP for variation in these estimates. The results suggest that GVCP raises economies' ERPT to export prices. In a second step, we obtain estimates of the ERPT to import prices analogously to that of export prices, and investigate how the former varies with the GVCP of economies' *trading-partners*. Consistent with the implications of the structural model, we find that ERPT to import prices is smaller for economies' whose trading partners exhibit larger ERPT to export prices due to higher GVCP. In the latter analysis, we control for other country characteristics in order to distinguish the role of GVCP on ERPT to import prices from that of the productivity of an economy's trading partners and the composition of its import bundle discussed above.

1 Introduction

A salient feature of the last two decades has been the decline in the pass-through of exchange rate changes to the price of imported goods (see Figure 1 and Campa et al., 2005; Marazzi et al., 2005; Ihrig et al., 2006; Sekine, 2006; ECB, 2016). Understanding the drivers of this decline is important as exchange rate pass-through (ERPT) is a key determinant of the domestic and international propagation of shocks, with implications for the movements of relative prices, the adjustment of external imbalances, business cycle co-movement and the effectiveness of monetary policy. The degree of ERPT is particularly relevant for central banks pursuing inflation targeting. For example, a lower ERPT to import prices weakens the exchange rate channel of domestic monetary policy. At the same time, a lower ERPT to import prices insulates at least in part the domestic economy from foreign monetary policy.

The literature has put forth several explanations for the decline in ERPT to import prices. In particular, first, Campa et al. (2005) find that for 23 OECD economies over the time period from 1975 to 2003 a larger share of imports has been accounted for by non-energy goods which exhibit lower ERPT to import prices. Second, Gust et al. (2010) set up a structural model with strategic complementarities in price setting and in which Foreign exporters which compete with Home firms prefer to let their mark-ups and thereby their Foreign-currency export price vary rather than adjusting their Home-currency export price in response to exchange rate changes. In the model, reductions in trade costs that deepen trade integration as well as a corresponding increase in exporters' productivity accentuate these strategic complementarities in price setting, and strengthen the willingness of exporters to vary their mark-ups in order to stabilise their prices in the importer's currency.

In this paper we consider another possible explanation for the decline in ERPT to import prices: The rise of global value chain participation (GVCP). Spurred by the decline in transportation costs, the adoption of trade-liberalising policies as well as advances in information and communication technologies, firms increasingly disperse stages of production across countries (see, for example, Baldwin, 2013; UNCTAD, 2013). By fragmenting production chains internationally, the share of intermediate goods in total trade has risen continuously relative to that of final goods (Antras, 2005). Data suggest that trade in intermediate goods and services nowadays accounts for 56% and 73% of overall trade flows in goods and services (Miroudot et al., 2009). Importantly for this paper, imported intermediates are not only used for the production of goods that are then absorbed domestically in final demand, but also in the production of exports. For example, Amiti et al. (2014) document that the largest importers at the same time also account for the largest share of an economy's exports. And Tintelnot et al. (2018) document that even if exporters do not use imported intermediates in their production, they are still strongly exposed to imported inputs through their domestic suppliers which use imported intermediates. In the context of ERPT, in this paper we argue that a larger share of imported intermediates in total inputs used in the production of an economy's exports implies a larger ERPT to *export* prices. In turn, the larger sensitivity of export prices to exchange rate changes implies a smaller sensitivity of import prices to exchange rate changes abroad.[1]

For example, assume the euro area imports intermediate inputs for the production of its exports from the US. Moreover, assume that — for the sake of simplicity — changes in the euro area's nominal exchange rate against the US dollar transmit fully and instantaneously into euro area import prices, and that US and euro area exporters keep their mark-ups constant. Now suppose the euro depreciates against the US dollar. Given the assumptions above, the costs of imported intermediates for euro area exporters will increase in response to the depreciation of the euro. Moreover, euro area exporters will increase their prices commensurately with the rise in their marginal costs stemming from the depreciation of the euro and the associated rise of the costs of imported intermediates. For the other side of the trade, the rise in the euro area's euro export prices is at least partly offset by the depreciation of euro, resulting in a dampened increase of US dollar import prices in the US. Thus, for a greater GVCP of the euro area, US importers will experience a dampened variation of US dollar import prices in response to variations of the exchange rate between the euro and the US dollar. Figure 1 shows that since 2000 GVCP has risen along with ERPT to import prices; GVCP is measured by advanced economies' ratio of domestic value-added in gross exports (VAX ratio), with lower values indicating stronger GVCP.

In this paper we first explore this mechanism in a structural two-country model. The main advantage of exploring this mechanism in a structural model is that it allows us to account for (international) general equilibrium effects. Specifically, in the example above the impact of GVCP on ERPT to import prices in the US was laid out assuming complete ERPT to import prices in the euro area. However, as the euro area also exhibits GVCP, by the same logic as for the US, ERPT to import prices would also decline in the euro area, potentially undoing the mechanism that produces a decline in ERPT to import prices in the US. In the model we lay out, GVCP is reflected by trade in intermediate goods which are used as inputs to production along with domestic goods. Economies' cross-border value chain integration varies with the steady-state share of imported intermediates in the intermediate input goods bundle. The model predicts that ERPT to export prices rises as the Home economy's value chain integration with the Foreign economy increases in terms of the share of imported intermediates in total intermediates. Moreover, the model predicts that due to the increase in ERPT to export prices in the Home economy induced by greater value chain integration with the Foreign economy, in the latter ERPT to import prices falls. In the baseline specification of the model we assume either flexible prices or sticky prices with producer-currency pricing (PCP), but we also explore alternative versions of the model in which prices are sticky and exporters subject to local and dominant-currency pricing (LCP and DCP).

[1] That variation in ERPT to export prices can cause variation in ERPT to import prices in the opposite direction abroad has also been discussed by Vigfusson et al. (2009). However, neither do Vigfusson et al. (2009) study the role of GVCP for shaping ERPT to export prices nor the variation in ERPT to import prices over time.

Against the background of these predictions from the structural model we explore the relationship between GVCP and ERPT to export and import prices in cross-country data. In particular, we first estimate ERPT to export prices for up to 22 advanced economies. We then assess to what extent differences in economies' GVCP — measured by the VAX ratio — can account for differences in the estimates of their ERPT to export prices. Consistent with the predictions from the model, the results suggest that greater Home GVCP is associated with higher ERPT to export prices. Second, we estimate ERPT to import prices and assess to what extent differences in the GVCP of economies' *trading partners* can account for differences in the estimates of economies' ERPT to import prices. Again consistent with the predictions from the model, we find that ERPT to import prices is smaller for economies' whose trading partners exhibit greater GVCP. In the latter analysis on the role of GVCP for ERPT to import prices, we control for alternative explanations for the secular decline in ERPT to import prices put forth in the literature, such as changes in the composition of import bundles towards goods with lower ERPT and the productivity of economies' trading partners measuring the strength of strategic complementarities (Campa et al., 2005; Gust et al., 2010).

The paper contributes and is related to existing literature on the implications of GVCP on ERPT. Campa and Goldberg (2008) use a structural model to show that greater use of imported intermediates raises ERPT to export prices, but do not relate the latter to a fall in ERPT to import prices abroad. Auer (2015) documents that ERPT to US producer prices in case of the government-controlled appreciation of the Renminbi vis-à-vis the US dollar between 2005 and 2008 was higher in sectors that rely more on imported inputs. Similarly, Auer and Mehrotra (2014) find that producer prices in the Asia-Pacific region respond more strongly to exchange rate changes in sectors in which the cost share of imported intermediates is higher. Finally, Casas (2019) examines Colombian micro-data and finds a positive correlation between ERPT to export prices and sectors' GVCP. However, neither Auer (2015), Auer and Mehrotra (2014) nor Casas (2019) are concerned with the evolution of ERPT over time, and do not relate the increase in ERPT to producer prices in case of higher GVCP to a decrease in ERPT to import prices abroad.[2] More closely related to our joint analysis of ERPT to export prices at home and import prices abroad, Amiti et al. (2014) document that firms with higher imported input intensity exhibit lower ERPT to destination-currency export prices. Additionally, Amiti et al. (2018) show that cross-sectional heterogeneity in imported input intensity and mark-up elasticity at the firm level imply muted ERPT to destination-currency export prices in the aggregate. However, due to their use of microeconomic models neither Amiti et al. (2014) nor Amiti et al. (2018) take into account international general equilibrium effects; also, they are not concerned with the secular decline in ERPT to import prices discussed in the macroeconomic literature.

[2] Casas (2019) explores the relationship between ERPT to import prices and an economy's *own* rather than its trading partners' GVCP, which in a small open economy model is predicted to be positive due to the presence of strategic complementarities (cf. Casas et al., 2017). As explained in more detail below, we do not consider this channel in the two-country framework in which own and trading partners' GVCP are positively related by construction due to balanced trade in the steady state, thereby mechanically giving rise to a positive association between ERPT to import prices and trading-partners' GVCP.

Ahmed et al. (2017) study whether GVCP has affected the elasticity of manufacturing exports to the real effective exchange rate through a mechanism similar to the one explored in this paper. Consistent with our findings for ERPT, Ahmed et al. (2017) find that GVCP has reduced the exchange rate elasticity of manufacturing exports in the late 1990s and 2000s. In contrast to Ahmed et al. (2017), we focus on the impact of GVCP on ERPT to export and import prices rather on export quantities. Finally, Rodnyansky (2018) builds a New Keynesian dynamic general equilibrium model to rationalise his empirical finding that depreciations do not benefit exporters, especially when they use a lot of imported intermediates. Again, in contrast to our paper Rodnyansky (2018) is not concerned with the role of GVCP for ERPT and its decline over time.

The remainder of the paper is organised as follows. Section 2 puts forth a structural model of international trade in intermediate and final goods to examine the impact of GVCP on ERPT to export prices as well as the consequences for trading partner's ERPT to import prices. In Section 3 we test the predictions of our theoretical model empirically. Finally, Section 4 concludes.

2 A structural two-country model with trade in intermediate goods

We first explore how changes in GVCP reflected in the varying use of imported intermediate inputs in production generate variations in ERPT to domestic-currency export and import prices. We consider a two-country framework instead of a multi-country framework with indirect production linkages for simplicity of exposition. However, for our empirical analysis we derive a multilateral representation of the predictions for the role of GVCP for ERPT obtained from the two-country model that accounts for the presence of multi-country, indirect production linkages in the data.

More specifically, the structural model we consider builds on the New Open Economy Macroeconomics literature (see, inter alia, Benigno and Thoenissen, 2003; Corsetti and Pesenti, 2005), but we additionally assume that economies engage in trade in intermediate inputs. Our benchmark model consists of two symmetric economies (Home and Foreign) of in general different size (n_H and n_F, with $n_H + n_F = 1$). Each economy consists of a continuum of firms that utilise labour and intermediate inputs to produce a differentiated, tradeable, country-specific good. The produced good is either consumed in the domestic economy, re-used as intermediate input in domestic production, or exported to the other economy, where it is again either consumed by households or used as input in production. We moreover assume incomplete financial markets at the international level and nominal rigidities in wages and prices. We explore the cases of flexible and sticky prices. While in the latter case we focus on PCP in the main text of the paper, we document in Appendix E that the relevant model predictions are qualitatively identical in the cases of LCP (Betts and Devereux, 2000; Devereux and Engel, 2003) and DCP (Gopinath, 2016; Casas et al., 2017; Boz et al., 2017).

2.1 Model structure

For expositional convenience and given that the structure of the two economies is symmetric we present only the equations for Home. Moreover, we abstract from shocks in the description of the model, but comment on their role for the impact of GVCP on ERPT in Section 2.5 below.

2.1.1 Household consumption and budget constraint

The utility function of the representative agent in Home is separable in consumption C_t and labour N_t and is given by

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\rho}}{1+\rho} \right), \tag{1}$$

where σ is the relative risk aversion, ρ the inverse elasticity of labour supply with respect to the real wage, and $\beta \in (0,1)$ the discount factor. We assume that Home and Foreign final goods are bundled into a consumption good according to

$$C_t = \left[(1-\delta)^{1/\theta} (C_{H,t})^{\frac{\theta-1}{\theta}} + \delta^{1/\theta} (C_{F,t})^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}, \tag{2}$$

where δ denotes the steady-state share of Foreign goods in Home final consumption and θ the consumption elasticity of substitution between goods produced in Home, $C_{H,t}$, and goods produced in Foreign, $C_{F,t}$. The specification of the consumption bundle in Equation (2) implies the consumer price index $P_t = \left[(1-\delta)(P_{H,t})^{1-\theta} + \delta (P_{F,t})^{1-\theta} \right]^{1/(1-\theta)}$. Households provide differentiated labour and face nominal rigidity in their wage income à la Calvo (1983), i.e. only a fraction $1-\varphi_w$ of all wages can be adjusted every period.

Assuming full use of resources, the inter-temporal budget constraint of a representative Home household is given by

$$\frac{B_{H,t}}{R_t P_t} + \frac{S_t B_{F,t}}{R_t^* P_t \Phi\left(\frac{S_t \overline{B}_{F,t}}{Y_t P_t}\right)} = \frac{B_{H,t-1}}{P_t} + \frac{S_t B_{F,t-1}}{P_t} + \frac{W_t}{P_t} N_t - C_t + \Pi_t + T_t, \tag{3}$$

where $B_{H,t}$ and $B_{F,t}$ denote holdings of Home-issued and Foreign-issued bonds, W_t the nominal wage, S_t the nominal bilateral exchange rate measured as the price of Home currency per unit of Foreign currency, Π_t redistributed profits, and T_t net taxes. We assume financial markets are incomplete such that Home and Foreign agents can hold Foreign-issued bonds. Additionally, in order to avoid having to model portfolio choice, we follow Benigno and Thoenissen (2003) and assume that only Home agents can hold Home-issued bonds. The function $\Phi(\cdot)$ represents a small financial intermediation cost that depends on the aggregate holdings of bonds issued abroad, $\overline{B}_F$, scaled by nominal GDP, $Y_t P_t$.[3] The profits from financial intermediation are reimbursed lump-sum to households. We assume Foreign households only have access to Foreign bonds, so their budget constraint differs accordingly.

2.1.2 Production

We abstract from the use of capital and assume that production uses only labour and an intermediate good bundle as inputs. Specifically, production of an individual firm f is given by

$$Y_t(f) = \left[\alpha_N N_t(f)^{\frac{\tau-1}{\tau}} + \alpha_M M_t(f)^{\frac{\tau-1}{\tau}}\right]^{\frac{\tau}{\tau-1}}, \tag{4}$$

where $N_t(f)$ denotes firm-specific labour demand, and $M_t(f)$ firm-specific demand for the intermediate input good bundle; the parameters α_N and α_M indicate the relative importance of labour and the intermediate input good bundle in production, and τ the elasticity of substitution between intermediate goods and labour. In turn, the intermediate input good bundle consists of Home intermediates, $M_{H,t}(f)$, and intermediates imported from Foreign, $M_{F,t}(f)$, aggregated according to

$$M_t(f) = \left[(1-\omega)^{1/\phi} M_{H,t}(f)^{\frac{\phi-1}{\phi}} + \omega^{1/\phi} M_{F,t}(f)^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}, \tag{5}$$

where the parameter ω represents the steady-state share of imported intermediate inputs in Home production, and ϕ the elasticity of substitution between domestically produced and imported intermediate inputs.

2.1.3 Price setting

We assume that in every period only a fraction $1-\varphi \in (0,1)$ of firms can adjust prices. Moreover, in order to explore ERPT under different assumptions regarding the export-pricing currency paradigm, we choose a setup that nests PCP, LCP and (with some modifications) DCP. In particular, we assume that each firm f sets a price for the Home and the Foreign market: Given the nominal exchange rate S_t, a firm f in Home sets a price $\widetilde{P}_{H,t}(f)$ for the Foreign market, which implies a Foreign-currency Home export price

$$P^*_{H,t}(f) = \widetilde{P}_{H,t}(f) \cdot S_t^{-\zeta^*}, \tag{6}$$

for $\zeta^* \in \{0,1\}$. This specification nests the case in which prices are set in the currency of the producer with $\zeta^* = 1$ (PCP), as well as the case in which prices are set in the currency of the

[3] The introduction of this cost ensures stationarity of the net foreign asset position (see, for instance, Schmitt-Grohé and Uribe, 2003). As in Benigno and Thoenissen (2003), we assume that the cost function $\Phi(\cdot)$ takes the value of unity when the net foreign asset position approaches its steady-state value, which we assume to be zero. We also assume the function $\Phi(\cdot)$ is differentiable and decreasing in the neighborhood of zero.

importer with $\zeta^* = 0$ (LCP). The price for goods consumed in Home is pre-set in Home currency $P_{H,t}(f)$. An individual firm chooses $P_{H,t}(f)$ and $\widetilde{P}_{H,t}(f)$ so as to maximise

$$E_0 \sum_{j=0}^{\infty} (\varphi\beta)^j \Lambda_{t,t+j} \times \left\{ \frac{P_{H,t}(f)}{P_{t+j}} \mathrm{Y}_{H,t+j}(f) + \frac{S_{t+j} P^*_{H,t+j|t}(f)}{P_{t+j}} Y^*_{H,t+j}(f) \right.$$
$$\left. - (1-\eta) MC_{t+j} \left[Y_{H,t+j}(f) + Y^*_{H,t+j}(f) \right] \right\}, \quad (7)$$

subject to the endogenous discount factor $\Lambda_{t,t+j}$ implied by the household optimisation problem, the consumer price level P_t, real marginal costs measured in terms of the aggregate consumption good, MC_t, a fiscal subsidy to all factors of production η, as well as Home and Foreign demand for goods of firm f given by $Y_{H,t}(f) = C_{H,t}(f) + M_{H,t}(f)$ and $Y^*_{H,t}(f) = C^*_{H,t}(f) + M^*_{H,t}(f)$.

2.1.4 Market clearing

Recall that output is used in Home and Foreign as intermediate input in production and to produce a composite final good. Therefore, and accounting for differences in country size, aggregate goods market clearing requires $Y_t = C_{H,t} + M_{H,t} + \frac{n_F}{n_H}(C^*_{H,t} + M^*_{H,t})$, and $Y^*_t = C^*_{F,t} + M^*_{F,t} + \frac{n_H}{n_F}(C_{F,t} + M_{F,t})$. For markets for Foreign-issued bonds to clear it is required that $n_H B_{F,t} + n_F B^*_{F,t} = 0$, and for Home-issued bonds that $B_t = 0$.

2.1.5 Monetary policy

We assume monetary policy targets consumer-price inflation and the output growth rate according to

$$R_t = R_{t-1}^{\nu_r} \cdot \left[\overline{R} \left(\frac{P_t/P_{t-1}}{\Pi} \right)^{\kappa_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\kappa_y} \right]^{(1-\nu_r)}, \quad (8)$$

where ν_r governs the degree of interest-rate smoothing, κ_π and κ_y denote coefficients multiplying consumer-price inflation and output growth, and Π the steady-state gross consumer-price inflation rate.

2.2 Model solution

In the steady state, markets clear, international trade is balanced and net inflation is zero. All firms which can re-set their prices choose the same price, and the fiscal subsidy η is set such that the distortion from monopolistic competition is offset.

2.3 Measuring GVCP in the model

In order to reflect economies' GVCP consistently across the model and the empirical analysis below, we consider the share of domestic value added in an economy's gross exports (i.e. the VAX ratio; see Johnson and Noguera, 2012). In Appendix C we show that given the assumption of symmetric production structures in Home and Foreign as well as balanced trade in the steady state, the steady-state VAX ratio of the Home economy is given by

$$VAX = \frac{\widetilde{\alpha}}{1-(1-\widetilde{\alpha})(1-\omega)+(1-\widetilde{\alpha}^{*})\omega^{*}}, \tag{9}$$

where $\widetilde{\alpha} \equiv \left[(\overline{W}/\overline{P})/(\overline{MC})\right]^{1-\tau} \alpha_N^{\tau}$ denotes the steady-state labour share in firms' total expenditure and $(1-\widetilde{\alpha})\omega$ the corresponding share of imported intermediates. Because trade is assumed to be balanced in the steady state and the production structure of Home and Foreign is symmetric, for a given steady-state share of imported intermediates in total intermediates in Home, ω, the corresponding steady-state share in Foreign is implied by $\omega^{*} = \omega\frac{n_H}{n_F}$; thus, assuming $\omega > 0$ implies and requires assuming $\omega^{*} > 0$ and vice versa.

The VAX ratio of Home is declining in the steady-state share of imported intermediates in total intermediates in Home, ω, as only a declining share of Home gross exports also represents Home value added. Hence, a smaller Home VAX ratio indicates stronger Home GVCP. Moreover, the VAX ratio of Home is declining in the steady-state share of imported intermediates in total intermediates in Foreign, ω^{*}, as Home value added being exported to serve as intermediate good in producing Foreign goods that are ultimately absorbed in Home is not counted as Home value added export.

2.4 Definition of structural ERPT

As in Corsetti et al. (2008) and Burlon et al. (2018) we define *structural* ERPT to domestic-currency export (import) prices as the *ceteris paribus* contemporaneous effect of a change in the bilateral nominal exchange rate on domestic-currency export (import) prices, namely

$$ERPT^{x} \equiv \left.\frac{\partial(\hat{p}^{*}_{H,t}+\hat{s}_t)}{\partial\hat{s}_t}\right|_{\boldsymbol{\psi}^{x}_{t}=const}, \tag{10}$$

and

$$ERPT^{m*} \equiv \left.\frac{\partial\hat{p}^{*}_{H,t}}{\partial(-\hat{s}_t)}\right|_{\boldsymbol{\psi}^{m^*}_{t}=const}, \tag{11}$$

where $\hat{p}^{*}_{H,t}$ denotes Home export prices quoted in Foreign currency, and $\boldsymbol{\psi}^{x}_{t}$ ($\boldsymbol{\psi}^{m^*}_{t}$) is a vector that collects all endogenous variables except for the contemporaneous exchange rate and Home export (Foreign import) prices; recall that the exchange rate is measured as the price of Home currency per unit of Foreign currency. The *ceteris paribus* assumption refers to the notion that the values of all endogenous variables except contemporaneous export and import prices as well as the exchange rate are held constant. These definitions of structural ERPT are also consistent with the definitions of ERPT considered in a large empirical literature that we follow in our empirical analysis and which motivates this paper (see, for example, Campa et al., 2005; Vigfusson et al., 2009; Bussière et al., 2014; Burstein and Gopinath, 2014). Moreover, as we show below this definition of structural ERPT boils down to the coefficient on the exchange rate in the Phillips curves for export prices. Notice that these definitions of structural ERPT have the interesting property that they are invariant to the shocks that induce variation in the exchange rate and the other endogenous variables.[4]

2.5 Relationship between GVCP and ERPT

We next explore how ERPT to import and export prices varies as economies' GVCP changes. For expositional clarity, we start with the case in which there is no nominal rigidity in goods prices, i.e. the case in which the choice of export pricing currency is inconsequential. After that we consider the case of sticky prices with PCP; in Appendix E we discuss the cases of sticky prices with LCP and DCP, which imply predictions that are qualitatively identical to those under PCP.

2.5.1 Flexible prices

In Appendix D we show that the log-linearised Phillips curve for Foreign-currency Home export prices can be expressed as

$$\hat{p}^*_{H,t} = \frac{\Omega^{-1}_{flex}}{1-(1-\widetilde{\alpha})(1-\omega)} \cdot \left[\widetilde{\alpha} w_t + \frac{(1-\widetilde{\alpha})\omega\widetilde{\alpha}^*}{1-(1-\widetilde{\alpha}^*)(1-\omega^*)} w^*_t - \widetilde{\alpha}\hat{s}_t\right], \tag{12}$$

where

$$\begin{aligned}
\Omega_{flex} &\equiv 1 - \frac{(1-\widetilde{\alpha})\omega}{1-(1-\widetilde{\alpha})(1-\omega)} \frac{(1-\widetilde{\alpha}^*)\omega^*}{1-(1-\widetilde{\alpha}^*)(1-\omega^*)} \\
&= 1-(1-VAC)(1-VAC^*),
\end{aligned} \tag{13}$$

[4] This can be seen below where the derivatives defined in Equations (10) and (11) are given by the coefficients on the exchange rate in the export and import price Phillips curves, which do not depend on the parameters governing the laws of motion of shocks. This is the case both when prices are flexible and when they are sticky under PCP, LCP or DCP.

and $VAC \equiv \widetilde{\alpha}/[1-(1-\widetilde{\alpha})(1-\omega)]$ is the Home value added content of output required to produce exports as a fraction of total exports (see, for example, Hummels et al., 2001).[5]

Against the background of Equations (10) and (11), structural ERPT for Home-currency Home export prices — i.e. the response of $\hat{p}^*_{H,t} + \hat{s}_t$ to changes in $\hat{s}_t$ *holding constant* w_t and w^*_t — is then given by

$$\begin{aligned} ERPT^x &= \Omega^{-1}_{flex}\left[-\frac{\widetilde{\alpha}}{1-(1-\widetilde{\alpha})(1-\omega)}\right]+1 \\ &= 1-\frac{VAC}{1-(1-VAC)(1-VAC^*)}. \end{aligned} \tag{14}$$

Accordingly, structural ERPT to Foreign-currency Foreign import prices is given by

$$\begin{aligned} ERPT^{m*} &= \Omega^{-1}_{flex}\left[\frac{\widetilde{\alpha}}{1-(1-\widetilde{\alpha})(1-\omega)}\right] \\ &= \frac{VAC}{1-(1-VAC)(1-VAC^*)}. \end{aligned} \tag{15}$$

Equations (14) and (15) indicate the standard result that in case of flexible prices and in the absence of trade in intermediate inputs and hence GVCP, i.e. when $VAC = VAC^* = 1$ as $\omega = \omega^* = 0$, there is complete ERPT to import prices and zero ERPT to export prices, i.e. $ERPT^x = 0$ and $ERPT^{m*} = 1$. In contrast, in the more general case with trade in intermediate inputs and hence GVCP both ERPT to import and export prices are positive but incomplete.[6]

It is instructive for grasping the intuition underlying the relationship between GVCP and ERPT to export prices to consider the polar case in which Home is a small open economy ($n_H \to 0$). In this case, taking Equation (14), noticing that $VAC^* \to 1$ and that $VAC \to VAX$ as $\omega^* \to 0$,

[5] The VAC ratio is close to unity when $\omega^* \to 0$, and equals $\widetilde{\alpha}$ when $\omega = 1$. Moreover, in general the VAX and VAC ratios differ. Specifically, in contrast to the VAC ratio, the VAX ratio is declining in the share of imported intermediate goods used in Foreign production ω^*, because Home value added being exported to serve as intermediate good in producing Foreign goods that are ultimately absorbed in Home is not counted as Home value added exports. However, the VAX ratio converges to the VAC ratio in the case in which the Foreign economy's share of imported intermediates in total intermediates used in production converges to zero, $\omega^* \to 0$, that is when Home is a small open economy (see Johnson and Noguera, 2012, for a discussion).

[6] It is interesting to point out that in the two-country model with fully flexible goods prices ($\varphi \to 0$) and fixed nominal wages, structural ERPT as defined in Equations (10) and (11) coincides with the correlation between the general equilibrium responses of local-currency import and export prices and the nominal exchange rate to standard shocks, such as preference, monetary policy, and uncovered interest (UIP) rate parity shocks; only technology shocks are an exception. Casas et al. (2017) note this finding in the context of a small open economy model. Under more general parameterisations with sticky wages and prices, the correlation between the general equilibrium responses of local-currency import and export prices and the nominal exchange rate depend on the shock (see Forbes et al., 2018). In the numerical solution of our model with a standard calibration, at least in case of shocks to the UIP condition the correlation between the general equilibrium responses of local-currency import and export prices and the nominal exchange rate is quantitatively similar to the structural ERPT measures in Equations (10) and (11). This is an important finding as it has been shown that most of the variation in exchange rates in the data is due to UIP shocks (see, for instance, Itskhoki and Mukhin, 2017).

we obtain for ERPT to Home-currency Home export prices

$$ERPT^x = 1 - VAX. \tag{16}$$

In particular, Equation (16) indicates that *stronger Home GVCP* — reflected by a lower Home VAX ratio — is associated with *higher ERPT to Home-currency Home export prices.* The intuition underlying this relationship is the following: Assuming for a moment complete ERPT to import prices in Home, when the Foreign currency depreciates the Home-currency price of goods imported by Home from Foreign falls. When Home firms use Foreign goods as intermediate inputs, their marginal costs decline, and so do Home-currency Home export prices, which are set as a constant mark-up over marginal costs. The drop in Home-currency Home export prices is stronger the larger the share of imported intermediate inputs in Home production, and hence the stronger Home GVCP.[7]

Turning to ERPT to import prices, it is again instructive for grasping the intuition underlying the relationship between GVCP and ERPT to import prices to consider the case in which Home is a small open economy ($n_H \to 0$). Specifically, noticing again that in this case $VAC^* \to 1$ and that $VAC \to VAX$ as $\omega^* \to 0$, in this case ERPT to Foreign-currency Foreign import prices in Equation (15) then boils down to

$$ERPT^{m*} = VAX. \tag{17}$$

Equation (17) indicates that *stronger Home GVCP* — reflected by a lower Home VAX ratio — is associated with *lower ERPT to Foreign-currency Foreign import prices.* The intuition underlying this relationship is the following: When the Foreign currency depreciates against the Home currency, Foreign-currency Foreign import prices increase. However, the rise in Foreign-currency Foreign import prices is weaker the more Home-currency Home export prices fall in response to the depreciation of the Foreign currency against the Home currency, i.e. the larger ERPT to export prices in Home. And as explained above, Home-currency Home export prices fall more strongly the larger the share of imported intermediate inputs in Home production, and hence the stronger Home GVCP.

The positive (negative) relationship between Home GVCP and ERPT to export prices in Home (ERPT to import prices in Foreign) indicated in Equations (16) and (17) remains qualitatively unchanged when assuming a country size for Home relative to Foreign that is not infinitesimally small, such that international, bilateral general equilibrium effects may arise. In particular, the solid black lines in Figure 2 plot the relationship between ERPT to Home-currency Home export prices and the Home VAX ratio as implied by Equation (14) as well as between ERPT to

[7] The polar assumption that Home is a small open economy is useful for laying out this mechanism as it precludes analogous effects in Foreign that would feed back to import prices in Home, which would unnecessarily complicate grasping the intuition. In particular, when Home is a small open economy Foreign does not use any relevant amount of intermediates imported from Home as inputs in production, so that Foreign marginal costs are unaffected by the depreciation of the Foreign against the Home currency. As a result, when Home is a small open economy, ERPT to Home-currency Home import prices is complete, which we had assumed at the outset.

Foreign-currency Foreign import prices and the Home VAX ratio as implied by Equation (15) for the case in which Home and Foreign are of identical size.[8,9]

2.5.2 Sticky prices

In Appendix D we show that under sticky prices and PCP structural ERPT to Home-currency Home export prices is given by[10]

$$ERPT^{x} = \Omega_{sticky}^{-1}\left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - 1\right] + 1, \tag{18}$$

where

$$\Omega_{sticky} \equiv \left[1 - \frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))}\frac{\kappa^{*}(1-\widetilde{\alpha}^{*})\omega^{*}}{(1+\beta^{*})+\kappa^{*}(1-(1-\widetilde{\alpha}^{*})(1-\omega^{*}))}\right],$$

with $\kappa \equiv (1-\beta\varphi)(1-\varphi)/\varphi$ and $\kappa^{*} \equiv (1-\beta^{*}\varphi^{*})(1-\varphi^{*})/\varphi^{*}$, and, accordingly, ERPT to Foreign-currency Foreign import prices is given by

$$ERPT^{m*} = -\Omega_{sticky}^{-1}\left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - 1\right]. \tag{19}$$

Analogous to the case of flexible prices, the black dashed lines in Figure 2 plot the relationship between Home GVCP and ERPT to Home-currency Home export as well as Foreign-currency

[8]Casas et al. (2017) consider a small open economy model with strategic complementarities and trade in intermediate goods. They find that in the small open economy there is a *rise* in *Home ERPT to import prices* as *Home* GVCP rises. The intuition is that as the Home currency depreciates and Home producers' marginal costs and hence prices rise due to the rise in the Home-currency price of imported intermediates, Foreign exporters raise their prices because they are reluctant to let their prices deviate from those of Home producers. Hence, Home-currency prices of Foreign exporters rise along with those of Home producers in response to a Home-currency depreciation, implying a *rise* in *Home ERPT to import prices* as *Home* GVCP rises. Notice that this mechanism grounded in strategic complementarities is different from the one we explore in this paper which produces a *decline* in *Home ERPT to import prices* as *Foreign* GVCP rises. A disadvantage of the two-country model we consider relative to a multi-country model is that due to the requirement of balanced bilateral trade in the steady state, a rise in Foreign GVCP *mechanically* implies a rise in Home GVCP (see Section 2.3). Therefore, in a two-country model with strategic complementarities a rise in Foreign GVCP that mechanically implies a rise in Home GVCP may thus eventually be associated with a rise in Home ERPT to import prices. In order to preclude this mechanical effect we abstract from strategic complementarities in the model. In the empirical analysis below we do however explore a robustness check in which we also control for Home GVCP when testing for the role of trading-partner GVCP for Home ERPT to import prices. In any case, notice that at least for advanced economies ERPT to import prices has fallen in the data, which is inconsistent with the effects that would result from a strengthening of strategic complementarities under GVCP.

[9]For the country sample we consider in Section 3, the cross-country median of the median across trading partners of countries' size relative to their trading partners is 1.2. For the sample excluding the US the ratio is 0.6.

[10]Consistent with the definition of ERPT in Equations (10) and (11), for the purpose of measuring the *ceteris paribus* contemporaneous effect of a change in the exchange rate on export and import prices, the values of past and expected future export and import prices and exchange rates that appear in the Phillips curves are held constant as well.

Foreign import prices for the case of PCP.[11] The relationships between GVCP and ERPT to export and import prices are qualitatively identical under sticky prices with PCP and flexible prices. Also, the mechanics underlying the relationship between ERPT and GVCP are identical under flexible prices and sticky prices with PCP. Quantitatively, however, stronger GVCP is associated only with smaller changes in ERPT in the case of sticky prices with PCP relative to the case of flexible prices. The reason for this is that under sticky prices in every period only a fraction $(1-\varphi) < 1$ of exporters can adjust prices.

Although the mechanisms are slightly different, in Appendix E we explain that the relationships between GVCP and ERPT to export and import prices are also qualitatively identical under sticky prices with LCP and even DCP. Specifically, Figure 2 shows that also under LCP and DCP Home ERPT to Home-currency export prices rises with Home GVCP and that Foreign ERPT to Foreign-currency import prices falls with Home GVCP. In the case of DCP we introduce the US a third economy; there are two versions of the relationship between ERPT and GVCP because we consider the cases of (1) a multilateral change in the value of the Foreign currency against the currency of Home and the US dollar as well as (2) a multilateral change in the value of the Home currency against the currency of Foreign and the US dollar.

It is interesting to discuss the level differences in ERPT across pricing paradigms for given values of GVCP. For example, ERPT to import prices is lower under LCP than PCP for all values of GVCP. This is intuitive as import prices are by assumption sticky in the currency of the importer under LCP. Notice that this also suggests another possible reason for the secular decline in ERPT to import prices in the data, namely a transition from PCP to in particular LCP. In fact, Chung (2016) sets up a structural model which predicts that exporters which depend more on imported intermediates prefer LCP over PCP. In particular, firms prefer LCP when using foreign-currency denominated imported intermediates because it is a natural hedge against nominal exchange rate risk. Hence, the analysis in Chung (2016) suggests that as GVCP rises, economies may switch from PCP to LCP, inducing a commensurate decline (increase) in global ERPT to import (export) prices. However, we think this alternative explanation is unlikely to be relevant for the decline in ERPT to import prices in the data that motivates our paper. In particular, the evidence suggests that the pricing currency of exports is rather stable, at least over the time horizons we consider (Gopinath, 2016). Moreover, the data in Gopinath (2016) and the analysis in Casas et al. (2017), Boz et al. (2017) as well as in Georgiadis and Schumann (2019) suggests that DCP rather than PCP has been the best description of export pricing in the data since at least the mid-1990s. And the analysis in Mukhin (2018) suggests that it is implausible for a switch from DCP to LCP to occur in a dynamic general equilibrium model of the international price system.[12]

[11] We set the discount factor to $\beta = 0.96$ — which matches annual frequency — and assume firms can adjust prices within 14 months, i.e. $\varphi = 0.1428$. Based on the average share of value added in total output in the World Input Output Database, the labour share is calibrated to $\widetilde{\alpha} = 0.51$.

[12] A similar argument applies to the predictions of Enders et al. (2018). Specifically, Enders et al. (2018) set up a structural model in which following a deepening of international financial integration agents use cross-border

3 Empirical analysis

3.1 Bringing the model predictions to the data

While the conceptual framework in the preceding section is based on a two-country model that only accounts for bilateral production linkages, in the data multi-country, indirect production linkages are pervasive. Therefore, we derive a multilateral representation of the predictions for the role of GVCP for ERPT obtained from the two-country model that accounts for multi-country, indirect production linkages in the data. Intuitively, we account for the role of such multi-country, indirect production linkages for ERPT in our empirical strategy by focusing on instances in which the Home economy's exchange rate changes *multilaterally* against all other currencies. For example, suppose that Germany exports intermediate goods to China, which in turn uses these to produce intermediate goods which are exported to Japan, where these are used to produce exports destined to Germany. In a multilateral empirical framework which exploits changes in the value of the effective euro exchange rate, it is irrelevant whether the mechanisms we described in the previous section play out bilaterally between Germany and one trading partner or indirectly through value chains in which Germany is the starting and end point after involving several trading partners.

Against this background, recall first that our theoretical analysis predicts that economy i's ERPT to the price of its exports to economy j depends on economy i's bilateral value chain integration with economy j, which implies that when estimating ERPT in an empirical analogue of Equation (12) from

$$p^x_{ijt} = \beta^x_{ij} \cdot s_{ijt} + \boldsymbol{w}'_{ijt}\boldsymbol{\gamma}^x_{ij} + u^x_{ijt}, \tag{20}$$

we expect β^x_{ij} to be an increasing function of economy i's bilateral value chain integration with economy j.[13] In other words, a first-order approximation of $\beta^x_{ij} = \beta^x_{ij}(VAX_{ij}, \boldsymbol{x}_{ij})$ that reflects the relationship shown in Figure 2 implies

$$\beta^x_{ij} = \beta^x + \alpha^x \cdot VAX_{ij} + \boldsymbol{x}'_{ij}\boldsymbol{\delta}^x + \nu^x_{ij}, \tag{21}$$

where we expect $\alpha^x < 0$. In order to generalise Equation (21) to a framework that accounts for multi-country, indirect production linkages, we first transform Equation (20) to a multilateral ERPT regression. Specifically, taking trade-weighted averages over economy i's trading partners

equity in addition to bond holdings in order to hedge against shocks. The resulting optimal portfolio includes a higher share of bonds denominated in foreign currency, and impacts the correlation structure of costs and sales in a way such that producers move from PCP towards LCP.

[13] In order to operationalise the *ceteris paribus* structural ERPT in Equations (10) and (11) in the case of sticky prices we need to control for expected future values of some variables in the Phillips curves. This can be achieved by replacing them by their linear projections on variables dated t — and the exchange rate dated $t-1$ — and earlier.

j in Equation (20) yields

$$\sum_j \omega_{ij} \cdot p^x_{ijt} = \sum_j \omega_{ij} \cdot \beta^x_{ij} \cdot s_{ijt} + \sum_j \omega_{ij} \cdot \boldsymbol{w}'_{ijt}\boldsymbol{\gamma}^x_{ij} + \sum_j \omega_{ij} \cdot u^x_{ijt}. \tag{22}$$

Exploiting the implication from the model in Section 2 that the slope coefficients β^x_{ij} and $\boldsymbol{\gamma}^x_{ij}$ in Equations (21) and (22) are determined by structural parameters that are uncorrelated with the variation of endogenous variables during their adjustment to temporary shocks implies that we can write Equation (22) as

$$p^x_{it} = \vartheta^x + \beta^x_i \cdot s_{it} + \boldsymbol{w}'_{it}\boldsymbol{\gamma}^x_i + u^x_{it}. \tag{23}$$

where p^x_{it} represents economy i's aggregate rather than bilateral export prices, and s_{it} its effective, trade-weighted exchange rate. Notice that this multilateral ERPT regression corresponds to those explored in a large empirical literature on ERPT (Campa et al., 2005; Vigfusson et al., 2009; Bussière et al., 2014; Burstein and Gopinath, 2014). Similarly, applying the same rationale and taking a weighted average across economy i's trading partners in Equation (21) we obtain

$$\beta^x_i = \beta^x + \alpha^x \cdot \overline{VAX}_i + \overline{\boldsymbol{x}}'_i\boldsymbol{\delta}^x + \overline{\nu}^x_i, \tag{24}$$

where overlined variables represent trade-weighted averages of bilateral variables.[14]

Since we are particularly interested in the time variation in ERPT, we cast Equations (23) and (24) into a time-varying framework

$$p^x_{it} = \theta^x_t + \beta^x_{it} \cdot s_{it} + \boldsymbol{w}'_{it}\boldsymbol{\gamma}^x_{it} + u_{it}, \tag{25}$$
$$\beta^x_{it} = \beta^x_t + \alpha^x \cdot \overline{VAX}_{it} + \overline{\boldsymbol{x}}'_{it}\boldsymbol{\delta}^x + \overline{\nu}^x_{it}. \tag{26}$$

Analogous regression equations for ERPT to import prices are given by

$$p^m_{it} = \vartheta^x_t + \beta^m_{it} \cdot s_{it} + \boldsymbol{h}'_{it}\boldsymbol{\gamma}^m_{it} + u^m_{it}, \tag{27}$$
$$\beta^m_{it} = \beta^m_t + \alpha^m \cdot \overline{VAX}^*_{it} + \overline{\boldsymbol{x}}'_{it}\boldsymbol{\delta}^m + \overline{\nu}^m_{it}, \tag{28}$$

where $\overline{VAX}^*_{it}$ is the trade-weighted average of economy i's trading-partners' bilateral VAX ratio with economy i, i.e. $\overline{VAX}^*_{it} \equiv \sum_j \omega_{ij} VAX_{ji,t}$, and where we expect $\alpha^m > 0$.

[14] Note that one could also approximate β^x_i in the multilateral Equation (23) rather than average across trading-partners in Equation (21) in order to arrive at Equation (24). However, it is not clear what the approximation error would be. In contrast, the approximation in case of Equation (21) is consistent with the bilateral model in the previous section, where we show that the relationship between β^x_{ij} and the bilateral VAX ratio is essentially linear (see Figure 2). Finally, notice that the trade-weighted average bilateral VAX ratio is given by $\sum_j \omega_{ij} va_{ij}/x_{ij}$, while the multilateral VAX ratio is given by $\sum_j va_{ij}/\sum_j x_{ij}$; hence, both VAX ratios are calculated using the *same* domestic value added and exports figures. We consider a robustness check in which we replace the trade-weighted average bilateral VAX ratio by the Home economy's multilateral VAX ratio vis-à-vis the rest of the world and vice versa.

3.2 Estimating ERPT to export and import prices

As common in the literature on ERPT (Campa et al., 2005; Vigfusson et al., 2009; Bussière et al., 2014; Burstein and Gopinath, 2014), we estimate ERPT to export and import prices in Equations (25) and (27) in first differences. In the vector of control variables $\Delta \boldsymbol{w}_{it}$ in the regression for ERPT to export prices in Equation (25) we include the contemporaneous value and lags of the quarter-on-quarter log-change of unit labour costs of economy i and the (trade-weighted) average of economy i's trading partners' GDP growth, as well as lags of the exchange rate and the dependent variable. The latter is measured by the quarter-on-quarter log-change of the export price unit value of economy i, and the exchange rate variable on the right-hand side by the quarter-on-quarter log-change of economy i's nominal effective exchange rate. In the vector of control variables $\Delta \boldsymbol{h}_{it}$ in the regression for ERPT to import prices in Equation (27) we include the contemporaneous value and lags of the quarter-on-quarter log-change of the (trade-weighted) average of trading partners' export prices as a proxy for trading partners' production costs and the quarter-on-quarter GDP growth of economy i, as well as lags of the exchange rate and the dependent variable. The latter is measured by the quarter-on-quarter log-change of the import price unit value of economy i. We estimate Equations (25) and (27) on ten-year rolling windows $\tau = 1, 2, \ldots, \mathcal{T}_i$ for the time period from 1986 to 2014 to obtain a sample of time-varying, country-specific estimates of ERPT to export and import prices. The first window spans the time period from 1986 to 1995 and the last the time period from 2005 to 2014. We thus have (at most) $\mathcal{T}_i = 20$ estimates of ERPT to export and import prices per economy. These are given by $\widehat{\beta}^{\ell}_{i\tau}$, $\ell \in \{x, m\}$, $\tau = 1, 2, \ldots, \mathcal{T}_i$.

3.2.1 Data and sample for the estimation of ERPT

Table 1 reports the set of advanced economies and the corresponding sample periods for which we estimate ERPT to export and import prices. The sample period spans at most 1986 to 2014. We only include advanced economies in our sample for which we also have data on GVCP in the World-Input-Output Database (WIOD; see below). We obtain quarterly data on import and export price indices as well as unit labour costs from the OECD. Data on nominal effective exchange rates, domestic GDP growth are taken from the IMF's International Financial Statistics. Consistent with the model in Section 2, we define the exchange rate in terms of domestic currency per unit of foreign currency. Thus, an increase in the nominal effective exchange rate index represents a depreciation of the domestic currency.[15]

[15] It is worthwhile to note that our empirical analysis is unlikely to be unduly affected by cross-border intra-firm pricing. Specifically, it is sometimes argued that intra-firm transfer prices are not allocative. In other words, the presumption that intra-firm prices are primarily accounting constructs carries with it the notion that transfer prices change less frequently and are less tied to fundamentals such as the exchange rate. However, Neiman (2010) documents that these two common presumptions about intra-firm transactions are at odds with the data, at least for the US. Specifically, Neiman (2010) provides evidence that is inconsistent with the hypothesis that intra-firm price changes are primarily driven by the desire to shift a firm's taxable income to countries with lower

3.2.2 Estimates of ERPT to export and import prices

Figure 3 presents time-averages of the estimates of ERPT to export and import prices for the economies in our sample obtained from the rolling regressions of Equations (25) and (27). Consistent with the findings in the literature, our estimates of ERPT to export and import prices exhibit notable cross-country heterogeneity (see Campa and Goldberg, 2005; Ihrig et al., 2006; Vigfusson et al., 2009; Frankel et al., 2012; Bussière et al., 2014). The cross-country average of ERPT to import and export prices is around 0.3, implying that a nominal effective depreciation of the domestic currency by one percent has on average been followed by an increase of import (export) prices by 0.3 percent in the sample period we study (see Table 2).

Figure 4 presents the results for the cross-country average of the time-varying estimates of ERPT to export and import prices based on the rolling regressions of Equations (25) and (27). The year indicated on the horizontal axis refers to the last year in the ten-year rolling window over which the corresponding ERPT estimate is obtained. Both ERPT to export and import prices have undergone noticeable changes, with the latter falling and the former increasing over time. This evidence is consistent with the hypothesis that at least some of the observed decline in ERPT to import prices stems from the rise in ERPT to export prices as predicted by the analysis in Section 2.

3.3 The role of the rise in GVCP for variation in ERPT over time

3.3.1 Export prices

In order to test the prediction from the model in Section 2 regarding the role of GVCP for ERPT to export prices, we estimate Equation (26) with the time-series dimension given by the rolling windows τ. In the vector of variables $\overline{\boldsymbol{x}}_{it}$ we include the volatility in domestic inflation as well as the nominal effective exchange rate (see Taylor, 2000; Devereux et al., 2004; Campa and Goldberg, 2005; Campa and Gonzalez Mìnguez, 2006). Moreover, we also include country and period fixed effects, which capture the effects of time-invariant, country specific as well as common, time-varying factors on economies' ERPT.[16]

tax rates, and that patterns in duration and exchange rate pass-through do not meaningfully differ when imports are sourced from countries with tax rates similar to the US compared with countries with highly dissimilar tax rates.

[16]One variable that is likely to be captured to a large degree by country fixed effects is the share of value chain integration that occurs within a currency area (De Soyres et al., 2018). Specifically, when considering the role of imported intermediate inputs used in production for ERPT, only intermediate inputs imported from a country which has a different currency would be relevant. For example, for a German producer, using inputs imported from the Netherlands would not have any effect on the ERPT, whereas inputs from China would instead dampen it. We consider a robustness check in which we consider only extra-euro area value chain integration for euro area economies. Another aspect that may be captured by country fixed effects is cross-country differences in the structure of invoicing currency of exports and imports as these do not change much over the time period horizons we consider in this paper (Gopinath, 2016). Nevertheless, we also consider a robustness check in which we

To the extent possible, the right-hand side variables in Equation (26) (and Equation (28) for ERPT to import prices below) are constructed as time-averages over the time period spanned by the corresponding rolling window over which ERPT on the left-hand side is estimated. For the variables that are derived from the WIOD, which provides data at annual frequency for the period from 1995 to 2014, the variables are measured as time averages over the longest possible time period spanned by the corresponding rolling window. In particular, for the first rolling window over which we estimate ERPT, which spans the time period from 1986 to 1995, the value of the VAX ratio we consider in the regression is the value for 1995 in the WIOD; for the second rolling window, which spans the time period from 1987 to 1996, the value of the VAX ratio we consider in the regression is the average for 1995 and 1996, and so on. For $\tau \geq 10$, i.e. from 2004 onwards, the time-averages of the VAX ratio are measured over precisely the same time windows as all other variables.

3.3.2 Import prices

Analogous to ERPT to export prices, for ERPT to import prices we estimate Equation (28). In the vector of variables $\overline{\boldsymbol{x}}^{*}_{it}$ we again include inflation and exchange rate volatility. Moreover, we also include variables reflecting alternative explanations for time-variation in ERPT to import prices put forth in the literature, namely the share of fuel imports in the economy's total imports, $fuel^{m}_{i\tau}$, as well as domestic firms' productivity relative to their trading partners average, $\Delta_{tp} tfp^{*}_{i\tau}$, measured by the economy-wide total factor productivity (see Campa et al., 2005; Gust et al., 2010).[17]

3.3.3 GVCP data

Consistent with the discussion in Section 2, we measure economy i's bilateral GVCP with economy j by the corresponding bilateral VAX ratio defined as the ratio of domestic value added in economy i's gross exports to economy j (Johnson and Noguera, 2012). In order to construct the VAX ratio for a broad panel of economies, we exploit the WIOD (Timmer et al., 2013; Stehrer et al., 2014). The WIOD provides global input-output tables at annual frequency for a large number of countries and sectors. The latest release from 2016 covers the time period from 2000 to 2014, while the previous release from 2013 covers the time period 1995 to 2011. We merge the data from the two releases to maximise our sample period.[18] While there are inconsistencies

control for ERPT to import prices at home as a proxy for incomplete ERPT due to local-currency invoicing when analysing ERPT to export prices, or for ERPT to import prices in economies' trading partners when analysing ERPT to import prices.

[17] Notice that we can calculate a relative TFP measure based on real TFP indices, i.e. $\Delta_{tp} ltfp^{*}_{i\tau} = ltfp_{i\tau} - ltfp^{*}_{i\tau}$, where $ltfp^{*}_{i\tau} \equiv \sum_{j} \omega_{ij} ltfp_{j\tau}$, as we add country fixed effects in Equations (26) and (28) so that we only exploit within-country time variation.

[18] Specifically, we derive all WIOD-based variables separately for the 2013 and the 2016 vintages. Then, we chain-link the values for the time period from 1995 to 1999 taken from the 2013 vintage with the values from the

in some definitions of sectors and country coverage across the two releases, these inconsistencies pertain mainly to the cross-sectional rather than the time-series dimension. Given that the identifying information in our fixed-effects panel regressions stems exclusively from the time-series dimension, we deem it appropriate to merge the two editions. In robustness checks below we confine the analysis to the latest WIOD edition.

The bilateral trade weights for the construction of variables which correspond to averages of an economy's trading partners are taken from the BIS. Data on total factor productivity measured at constant prices is taken from the Penn World Tables. The share of fuel imports (exports) in total imports (exports) is taken from the World Developments indicators and are based on United Nations COMTRADE data. The sample used for the estimation of Equations (26) and (28) eventually spans the time period from 1995 to 2014. Table 2 provides summary statistics for the main variables that we include the regressions.

3.3.4 Results

Column (1) in Table 3 reports the results of the regression for the determinants of differences in ERPT to export prices in Equation (26).[19] The coefficient estimate of the VAX ratio is statistically significant and has the expected negative sign. The results are thus consistent with the prediction from the structural model in Section 2 that higher GVCP raises the sensitivity of an economy's export prices in the exporter's currency to exchange rate movements. Quantitatively, the coefficient estimate implies that the decline in the average VAX ratio over the sample period by 5 percentage points (see Figure 1) raised ERPT to export prices by about 5 percentage points (-0.05 $\times$ -0.975, see column (1) in Table 3), which corresponds to about one third of its increase of about 15 percentage points in the sample period (see Figure 4).

Column (1) in Table 4 reports the results of the regression for the determinants of cross-country differences in ERPT to import prices in Equation (27). The coefficient estimate for the trade-weighted average of economy i's trading-partners' bilateral VAX ratio is statistically significant and has the expected positive sign. Specifically, the results are consistent with the prediction from the structural model in Section 2 that an economy exhibits lower ERPT to its import prices when its trading partners exhibit greater GVCP as measured by their bilateral VAX ratios. Quantitatively, the coefficient estimate implies that the decline in the average trading-partner VAX ratio over the sample period by 5 percentage points reduced ERPT to import prices by about 10 percentage points (-0.05 $\times$ 2.045, see column (1) in Table 4), which corresponds to almost 50% of its decline of about 20 percentage points in the sample period (see Figure

time period from 2000 to 2014 taken from the 2016 edition. When we compare the two time series across the vintages for the overlapping time periods, the cross-vintage correlation is very large.

[19]We use Driscoll and Kraay (1998) standard errors which are robust to heteroskedasticity and autocorrelation as well as cross-section dependence. Moreover, in order to save space, we only report coefficient estimates for the VAX ratio and for those variables that reflect alternative explanations for the decline in ERPT to import prices.

4). The coefficient estimates on the share of fuel imports and relative productivity also have the expected signs and are statistically significant. Specifically, we find that ERPT to Home-currency import prices is higher if a higher share of imports is accounted for by fuel products, whose prices exhibit a higher ERPT (see Campa et al., 2005). Moreover, we find that ERPT to Home-currency import prices is higher when Home importers are more productive than their Foreign competitors (Gust et al., 2010).

3.4 Robustness

A number of robustness checks are reported in columns (2) to (6) in Table 3 and columns (2) to (7) in Table 4. First, we replace the estimate of the ERPT to export and import prices by zero if it is not statistically significantly different from zero. The results reported in column (2) of Tables 3 and 4 are very similar to those from the baseline, although as one would expect the R-squared drops markedly.

Second, recall that in the baseline we use the combination of the 2013 and the 2016 WIOD releases, arguing that the inconsistencies in the definitions of sectors pertain mainly to the cross-sectional rather than the time-series dimension and are hence unlikely to affect to our results. For a robustness check we restrict the sample to the latest WIOD edition stretching from 2000 to 2014. The results for the regressions of Equations (26) and (27) reported in column (3) of Tables 3 and 4 are qualitatively unchanged from the baseline.

Third, recall that while only intermediate inputs imported from a country which has a different currency are relevant for ERPT in the mechanism we explore in this paper, in the baseline we use a measure of value chain integration that also accounts for production linkages that occur within a currency area, arguing that this is likely to be captured by country fixed effects. For a robustness check in the calculation of the average bilateral VAX ratios for euro area economies we disregard their bilateral VAX ratios with other euro area economies. The results reported in column (4) of Tables 3 and 4 are very similar to those from the baseline.

Fourth, we consider the Home economy's VAX ratio vis-à-vis the rest of the world instead of the average bilateral VAX ratio with an economy's trading partners in Equation (26) and the rest of the world's VAX ratio with an economy instead of the average trading-partners' bilateral VAX ratio with an economy in Equation (28). The results reported in column (5) of Tables 3 and 4 are consistent with those from the baseline.

Fifth, we test whether our results are driven by omitted heterogeneity in export-currency pricing paradigms rather than differences in GVCP. Potentially, this is an important robustness check as Chung (2016) as well as Mukhin (2018) have shown that the choice of export-pricing currency may be driven by exporters' cost structure in terms of the importance of imported intermediates. In this case, even though GVCP would still be the ultimate reason for differences in ERPT, the mechanism would work indirectly through differences in the choice of pricing currency rather than directly through differences in the use of imported intermediates. In order to account for the possible role of differences in export-pricing currencies, we include in our baseline specification in Equation (26) as an additional control the estimated ERPT to import prices, $\widehat{\beta}^{m}_{i\tau}$, to account for variations in ERPT to export prices that are driven by — time-varying, recall that we include country fixed effects — differences in ERPT to import prices *over and above* GVCP, such as differences in local vs. foreign-currency pricing of imports. For example, for a given level of mark-ups, a higher level of ERPT to import prices — for instance reflecting a low share of imports priced in the domestic currency, which echoes the finding in Section 2 that ERPT differs across PCP, LCP and DCP for a given level of GVCP — leads to a stronger decline of the local-currency costs of imported intermediates in response to an appreciation of the domestic currency.[20] Likewise, we add to our baseline specification in Equation (27) the estimated ERPT to import prices of economy i's trading partners. The results reported in column (6) of Tables 3 and 4 are qualitatively unchanged relative to the baseline. Moreover, the signs of the coefficients on the ERPT estimates are consistent with what one would expect: Higher ERPT to import prices raises ERPT to export prices, and higher ERPT to import prices in an economy's trading partners lowers domestic ERPT to import prices.

Finally, in the regressions for the determinants of ERPT to import prices in Table 4 we additionally include on the right-hand side the domestic economy's average bilateral VAX with its trading partners in order to control for the possible effect of strategic complementarities under GVCP as discussed by Casas et al. (2017). Recall that in the presence of strategic complementarities and GVCP a depreciation of the Home currency that raises marginal costs of domestic producers induces Foreign exporters to raise their Home-currency prices, raising Home ERPT to import prices and thus generating a positive relationship between *Home* GVCP and Home ERPT to import prices. Qualitatively, our estimates in column (7) in Table 4 are consistent with the predictions from this mechanism. Most importantly, however, our baseline results concerning the relationship between *trading-partner* GVCP and Home ERPT to import prices are unchanged.

4 Conclusion

This paper draws a causal link between the rise of global value chains and the decline of ERPT to import prices. We first illustrate in a structural two-country model with trade in intermediate goods and staggered price setting that higher GVCP results in higher ERPT to local-currency export prices in the Home economy. In turn, the reduction in the Home economy's local-currency export prices as it increases its GVCP translates into a lower ERPT to local-currency import

[20] Boz et al. (2017) as well as Chen et al. (2018) document that ERPT estimates are much higher when import prices are regressed on the exchange rate of the local currency against the dominant/vehicle currency instead of or in addition to the currency of the trading partner.

prices in its trading partners. Second, using input-output data for a sample of 22 advanced economies over the time period from 1995 to 2014, we document that in line with the theoretical predictions (1) estimates of economies' ERPT to local-currency export prices are increasing in economies' GVCP, and (2) estimates of economies' ERPT to local-currency import prices are decreasing in the GVCP of economies' trading partners. Against the background of the large share of intermediate goods in total trade and the international integration of global production chains, our findings have implications for the understanding of important issues in international macroeconomics, such as the movements of relative prices, the adjustment of global imbalances, business cycle co-movements and the transmission and effectiveness of monetary policy.

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A Tables

Table 1: Sample periods for estimation of ERPT to export and import prices

	Sample period	
Australia	1986 Q1	2014Q4
Austria	1995 Q1	2014Q4
Belgium	1995 Q1	2014Q4
Canada	1986 Q1	2014Q4
Denmark	1995 Q1	2014Q4
Finland	1995 Q1	2014Q4
France	1995 Q1	2014Q4
Germany	1995 Q1	2014Q4
Greece	1995 Q1	2014Q4
Ireland	1995 Q1	2014Q4
Italy	1995 Q1	2014Q4
Japan	1994 Q1	2014Q4
Netherlands	1995 Q1	2014Q4
Norway	1986 Q1	2014Q4
Portugal	1995 Q1	2014Q4
Spain	1995 Q1	2014Q4
Sweden	1993 Q1	2014Q4
Switzerland	1986 Q1	2014Q4
USA	1986 Q1	2014Q4
UK	1986 Q1	2014Q4

Table 2: Summary statistics

	mean	sd	min	max	count
ERPT to export prices	0.27	0.24	0.00	0.80	250
ERPT to import prices	0.28	0.26	-0.14	0.89	283
Average bilateral VAX	0.76	0.14	0.41	1.03	271
Trading partner average bilateral VAX	0.80	0.06	0.67	0.93	286
VAX	0.80	0.10	0.41	0.93	271
RoW VAX	0.79	0.13	0.32	0.95	271
Exported fuel share	11.00	15.04	0.37	70.00	286
Imported fuel share	13.25	6.36	3.50	37.61	286
Real TFP rel. to trading partner	0.01	0.04	-0.09	0.20	286

Table 3: Determinants of ERPT to export prices

	(1) Baseline	(2) Insign. to zero	(3) Latest WIOD	(4) VAX ex. intra-EA	(5) RoW	(6) Invoicing
Average bilateral VAX	-0.975***	-0.940***	-0.708***			-0.653***
	(0.00)	(0.01)	(0.00)			(0.00)
Average bil VAX (ex. intra-EA GVC)				-0.506**		
				(0.02)		
VAX					-1.537**	
					(0.03)	
ERPT to import prices						0.396***
						(0.00)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	260	260	235	260	260	252
R-squared	0.32	0.24	0.17	0.29	0.29	0.29
No. of Countries	20	20	20	20	20	20

p-values in parentheses

Driscoll-Kraay standard errors.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Determinants of ERPT to import prices

	(1) Baseline	(2) Insign. to zero	(3) Latest WIOD	(4) VAX ex. intra-EA	(5) RoW	(6) Invoicing	(7) Home Vax
Trad part avg bilateral VAX	2.045***	1.526***	1.634***			2.662***	2.226***
	(0.00)	(0.01)	(0.00)			(0.00)	(0.00)
Imported fuel share	0.016***	0.014***	0.016***	0.014***	0.013***	0.015***	0.015***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Real TFP rel. to trading partner	0.794***	0.484**	1.015***	0.807***	0.925***	0.685***	0.848***
	(0.00)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Trad. partner avg bil VAX				2.501***			
(ex intra-EA GVC)				(0.00)			
RoW VAX					0.573*		
					(0.08)		
Trad. partner ERPT imp prices						-0.472***	
						(0.01)	
Average bilateral VAX							-0.077
							(0.70)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	301	301	268	301	273	301	273
R-squared	0.27	0.18	0.27	0.27	0.32	0.29	0.35
No. of Countries	22	22	22	22	21	22	21

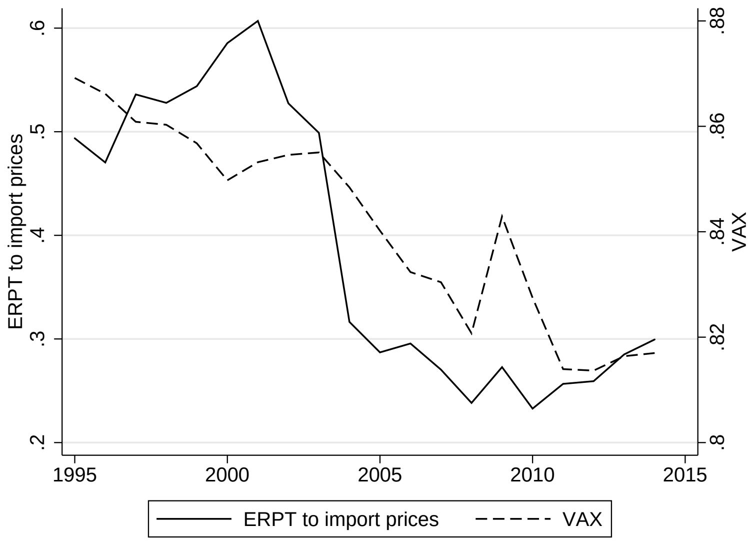
p-values in parentheses

Driscoll-Kraay standard errors

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

B Figures

Figure 1: ERPT to import prices and the VAX



Note: Cross-country averages of ERPT estimates and VAX ratios.

Figure 2: Structural Home ERPT to Home-currency export prices $ERPT^x$ and Foreign ERPT to Foreign-currency import prices $ERPT^{m*}$ with varying GVCP of the Home economy (expressed by the Home VAX ratio that varies in the share of imported intermediate goods in total intermediate goods used in production; a lower VAX ratio indicates higher GVCP). Home and Foreign are of equal size.

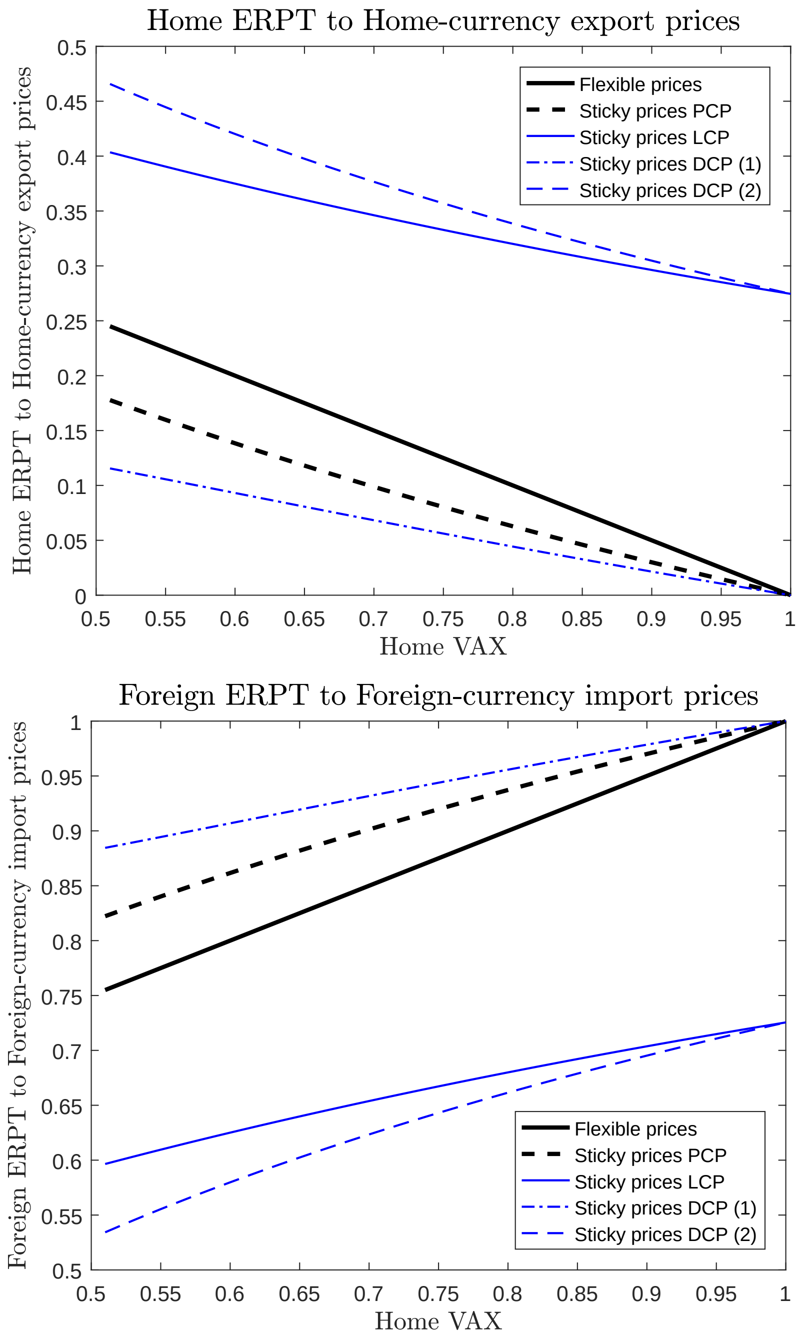


Figure 3: ERPT to export and import prices

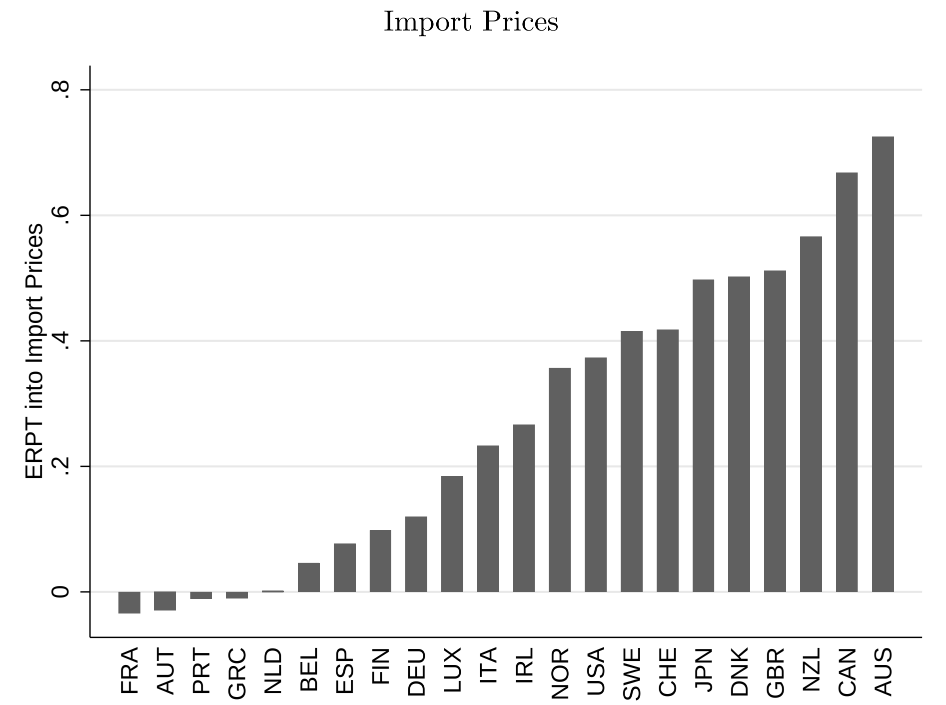
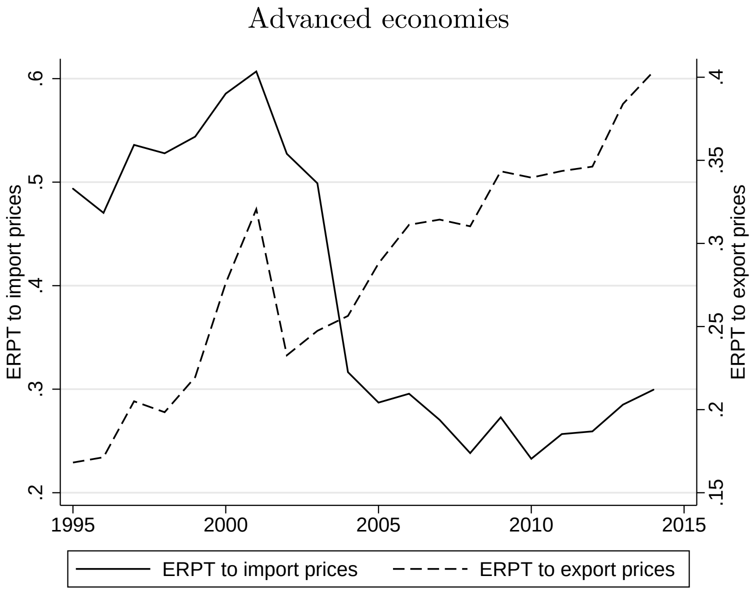


Figure 4: ERPT to Import and Export Prices



C Calibration of the VAX ratio

Johnson and Noguera (2012) compute the VAX for the case of a two-country model

$$VAX = \frac{1 - a_{11} - a_{21}}{1 - a_{11}} \left(\frac{x_{12} - a_{12} y_{21}}{x_{12}} \right) \tag{C.1}$$

$$x_{12} - a_{12} y_{21} = (1 - a_{11}) y_{12} \tag{C.2}$$

where $a_{ij} \forall ij$ denotes the amout of intermediate inputs that are produced in country i and serve as input in production in country j, expressed as a share of total output in country j. x_{12} are gross exports from country i to country j, y_{21} is output of country 2 absorbed in country 1 and y_{12} is output of country 1 absorbed in country 2.

In the calibration of our two-country model, we have $a_{11} = (1-\tilde{\alpha})(1-\omega)$, $a_{12} = (1-\tilde{\alpha}^*)\omega^*$, $a_{21} = (1-\tilde{\alpha})\omega$. Also, in steady state, we assume that the two countries have a symmetric production structure and balanced trade $y_{12} = y_{21}$.

By substitution of equation (C.2) into equation (C.1), one obtains

$$VAX = \frac{1 - a_{11} - a_{21}}{1 - a_{11}} \frac{(1 - a_{11}) y_{12}}{(1 - a_{11} + a_{12}) y_{12}} = \frac{1 - a_{11} - a_{21}}{1 - a_{11} + a_{12}}. \tag{C.3}$$

Plugging in a_{ij} $\forall ij$, we get

$$VAX = \frac{\tilde{\alpha}}{1 - (1 - \tilde{\alpha})(1 - \omega) + (1 - \tilde{\alpha}^*)\omega^*}. \tag{C.4}$$

D Structural ERPT in the calibrated model

ERPT to local-currency export prices (ERPT to local currency import prices) is defined as the contemporaneous effect of a one percent change in the bilateral nominal exchange rate for local-currency export prices (local-currency import prices), other things equal (as in Corsetti et al., 2008; Burlon et al., 2018). In the following, we derive ERPT for the case of fully flexible prices and for the the case of sticky prices with different assumptions regarding the denomination of currencies. Under producer currency pricing (PCP) exports are always denominated in exporter's currency, whereas with local currency pricing (LCP), exports are priced in destination currency. The dominant currency paradigm (DCP) refers to the case that Home and Foreign exports are priced in US dollar as a third-party currency. Variables are expressed in log-linearised form which is expressed by hats and small letters.

D.1 Flexible goods prices

In the case of flexible prices ($\varphi \to 0$) the NK Phillips curve for Home local-currency export prices is

$$p_{H,t} = n\hat{m}c_t,$$

$$n\hat{m}c_t = \tilde{\alpha}w_t + (1-\tilde{\alpha})(1-\omega)\hat{p}_{H,t} + (1-\tilde{\alpha})\omega(s_t + \hat{p}^*_{F,t}).$$

with $n\hat{m}c_t = \hat{m}c_t + \hat{p}_t$ describing the evolution of nominal marginal cost denominated in local-currency. Rearranging gives

$$p_{H,t} = \frac{1}{1-(1-\tilde{\alpha})(1-\omega)}\left[\tilde{\alpha}w_t + (1-\tilde{\alpha})\omega(s_t + p^*_{F,t})\right].$$

The corresponding expression for Foreign local-currency import prices is

$$p^*_{H,t} = \frac{1}{1-(1-\widetilde{\alpha})(1-\omega)}\left(\widetilde{\alpha}w_t + (1-\widetilde{\alpha})\omega p^*_{F,t} - \widetilde{\alpha}\hat{s}_t\right).$$

Foreign-produced foreign-consumed goods prices in local currency evolve according to

$$p^*_{F,t} = \frac{\widetilde{\alpha}^*}{1-(1-\widetilde{\alpha}^*)(1-\omega^*)}w^*_t + \frac{(1-\widetilde{\alpha}^*)\omega^*}{1-(1-\widetilde{\alpha}^*)(1-\omega^*)}p^*_{H,t}.$$

Substitution of the two equations results in

$$\hat{p}^*_{H,t} = \frac{\Omega^{-1}_{flex}}{1-(1-\widetilde{\alpha})(1-\omega)}\left(\widetilde{\alpha}w_t + \frac{(1-\widetilde{\alpha})\omega\widetilde{\alpha}^*}{1-(1-\widetilde{\alpha}^*)(1-\omega^*)}w^*_t - \widetilde{\alpha}\hat{s}_t\right),$$

where $\Omega_{flex} = 1 - \frac{(1-\widetilde{\alpha})\omega}{1-(1-\widetilde{\alpha})(1-\omega)}\frac{(1-\widetilde{\alpha}^*)\omega^*}{1-(1-\widetilde{\alpha}^*)(1-\omega^*)}$.

Fixing nominal wages in Home and Foreign at their current levels ($w_t = 0$, and $w^*_t = 0$) gives following expression for ERPT to Foreign's local-currency import prices

$$ERPT^{m*} = \Omega^{-1}_{flex}\frac{\widetilde{\alpha}}{1-(1-\widetilde{\alpha})(1-\omega)} = \frac{\hat{p}^*_{H,t}}{-\hat{s}_t}. \tag{D.1}$$

Similarly, ERPT to Home local-currency export prices is

$$ERPT^{x} = 1 - \Omega^{-1}_{flex}\frac{\widetilde{\alpha}}{1-(1-\widetilde{\alpha})(1-\omega)} = \frac{\hat{p}_{H,t}}{\hat{s}_t}. \tag{D.2}$$

D.2 PCP

We start with defining $\kappa \equiv \frac{(1-\beta\varphi)(1-\varphi)}{\varphi}$, $\kappa^* \equiv \frac{(1-\beta^*\varphi^*)(1-\varphi^*)}{\varphi^*}$, and $\Omega_{sticky} \equiv \left\{1 - \frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))}\frac{\kappa^*(1-\widetilde{\alpha}^*)\omega^*}{(1+\beta^*)+\kappa^*(1-(1-\widetilde{\alpha}^*)(1-\omega^*))}\right\}$. The NK Phillips curve for Home-produced Home-consumed goods is given by

$$\hat{p}_{H,t}(1+\beta+\kappa) = \beta E_t \hat{p}_{H,t+1} + \hat{p}_{H,t-1} + \kappa n\hat{m}c_t,$$

$$n\hat{m}c_t = \widetilde{\alpha} w_t + (1-\widetilde{\alpha})(1-\omega)\hat{p}_{H,t} + (1-\widetilde{\alpha})\omega(\hat{p}_{F,t})$$

with $n\hat{m}c_t = \hat{m}c_t + \hat{p}_t$ describing the evolution of nominal marginal cost denominated in local-currency.

Substitution gives

$$n\hat{m}c_t = \widetilde{\alpha} w_t + \frac{(1-\widetilde{\alpha})(1-\omega)}{(1+\beta+\kappa)}\left[\beta E_t \hat{p}_{H,t+1} + \hat{p}_{H,t-1} + \kappa n\hat{m}c_t\right] + (1-\widetilde{\alpha})\omega(\hat{p}_{F,t}).$$

Rearranging (and ignoring nominal wage, technology as well as all lag and lead terms) results in

$$n\hat{m}c_t = ... + \frac{(1+\beta+\kappa)(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))}(\hat{p}_{F,t}).$$

Equivalently, for Foreign

$$n\hat{m}c^*_t = ... + \frac{(1+\beta^*+\kappa^*)(1-\widetilde{\alpha}^*)\omega^*}{(1+\beta^*)+\kappa^*(1-(1-\widetilde{\alpha}^*)(1-\omega^*))}(\hat{p}^*_{H,t}).$$

The NK Phillips curves for Home-produced Foreign-consumed goods as well as Foreign-produced Home-consumed goods are given by

$$(\hat{p}^*_{H,t} + \hat{s}_t)(1+\beta+\kappa) = \beta E_t(\hat{p}^*_{H,t+1} + \hat{s}_{t+1}) + (\hat{p}^*_{H,t-1} + \hat{s}_{t-1}) + \kappa n\hat{m}c_t,$$

$$(\hat{p}_{F,t} - \hat{s}_t)(1+\beta^*+\kappa^*) = \beta^* E_t(\hat{p}_{F,t+1} - \hat{s}_{t-1}) + (\hat{p}_{F,t-1} - \hat{s}_{t-1}) + \kappa^* n\hat{m}c^*_t.$$

Rearranging (and ignoring nominal wage, technology as well as all lag and lead terms) results in

$$\hat{p}^*_{H,t} = ... + \frac{\kappa}{1+\beta+\kappa}\left[\frac{(1+\beta+\kappa)(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))}(\hat{p}_{F,t})\right] - \hat{s}_t.$$

After substitutions we obtain Foreign ERPT to local currency import prices

$$\hat{p}^*_{H,t}\Omega_{sticky} = ... + \hat{s}_t\left\{\frac{\kappa}{1+\beta+\kappa}\frac{(1+\beta+\kappa)(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - 1\right\},$$

$$ERPT^{m*} = (-1) * \Omega^{-1}_{sticky}\left\{\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - 1\right\}. \tag{D.3}$$

With some more steps, one can also obtain Home ERPT to local currency export prices

$$ERPT^x = \Omega^{-1}_{sticky}\left\{\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - 1\right\} + 1. \tag{D.4}$$

E Structural ERPT in case of LCP and DCP

E.1 LCP

The NK Phillips curves for Home-produced Foreign-consumed goods as well as Foreign-produced Home-consumed goods are given by

$$\hat{p}^*_{H,t}(1+\beta+\kappa) = \beta E_t \hat{p}^*_{H,t+1} + \hat{p}^*_{H,t-1} + \kappa n\hat{m}c_t - \kappa \hat{s}_t,$$

$$\hat{p}_{F,t}(1+\beta^*+\kappa^*) = \beta^* E_t \hat{p}_{F,t+1} + \hat{p}_{F,t-1} + \kappa^* n\hat{m}c^*_t + \kappa^* \hat{s}_t.$$

Rewriting the equations (and ignoring nominal wage, technology as well as all lag and lead terms) yields

$$\hat{p}_{F,t} = ... + \frac{\kappa^*}{1+\beta^*+\kappa^*} n\hat{m}c^*_t + \frac{\kappa^*}{1+\beta^*+\kappa^*}\hat{s}_t,$$

$$\hat{p}^*_{H,t} = ... + \frac{\kappa}{1+\beta+\kappa} n\hat{m}c_t - \frac{\kappa}{1+\beta+\kappa}\hat{s}_t.$$

Plugging in nominal marginal cost (see Section D.2) gives Foreign ERPT to local-currency import prices

$$\hat{p}^*_{H,t}\Omega_{sticky} = ... + \hat{s}_t \left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} \frac{\kappa^*}{1+\beta^*+\kappa^*} - \frac{\kappa}{1+\beta+\kappa} \right],$$

$$ERPT^{m*} = (-1) * \Omega^{-1}_{sticky} \left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} \frac{\kappa^*}{1+\beta^*+\kappa^*} - \frac{\kappa}{1+\beta+\kappa} \right]. \quad \text{(E.1)}$$

Home ERPT to local currency export prices is given by

$$ERPT^{x} = \Omega^{-1}_{sticky} \left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} \frac{\kappa^*}{1+\beta^*+\kappa^*} - \frac{\kappa}{1+\beta+\kappa} \right] + 1. \quad \text{(E.2)}$$

Figure 2 documents that the relationships between GVCP and ERPT to export and import prices are also qualitatively identical under LCP. In order to grasp the underlying intuition, assume again for simplicity that Home is small relative to Foreign. As regards ERPT to Home export prices, notice first that under LCP and an appreciation of the Home currency, Home-currency export prices mechanically fall, implying a large ERPT to export prices in Home. This mechanical ERPT to export prices in Home is mitigated by price increases by those Home exporters which can adjust prices, which is optimal for them because they aim at stabilising mark-ups over marginal costs. Importantly, this mitigation is obviously less relevant if marginal costs of Home exporters fall in response to the appreciation of the Home currency. The mechanism through which Home marginal costs fall in response to the appreciation of the Home currency is as follows. Analogously to Home, the appreciation of the Home currency and the stickiness of Foreign export prices in Home currency imply that Foreign-currency export prices in Foreign rise. As Foreign exporters also aim at stabilizing mark-ups, those Foreign exporters which can adjust reduce their Foreign-currency prices. When Home uses imported intermediates from Foreign, the reduction in Foreign-currency export prices by those Foreign exporters which can adjust implies a fall in Home-currency import prices, and therefore a fall in Home marginal costs. Hence, Home ERPT to export prices rises with Home GVCP under LCP. Understanding the relationship between Home GVCP and ERPT to import prices in Foreign under LCP is simpler. Specifically, as a stronger Home GVCP implies a stronger reduction in Home-currency export prices in Home, the already only small increase in Foreign-currency import prices in Foreign is mitigated further. Hence, Home GVCP reduces ERPT to import prices in Foreign also under LCP.

E.2 DCP

In order to explore the case of DCP, we consider an extension of the benchmark model presented above in which we introduce the US as a third economy.[21] Home, Foreign and the US differ in size as measured by n_H, n_F and n_{US}, with $n_H + n_F + n_{US} = 1$. The structure of each economy in the three-country model is identical to the structure of an economy in the benchmark two-country model.

Under DCP we assume that Home and Foreign firms price their exports in US dollar.[22] Specifically, a firm f in Home sets prices for domestically consumed goods $P_{H,t}(f)$ and for exported goods $\widetilde{P}_{H,t}(f)$ so as to maximise

$$E_0 \sum_{j=0}^{\infty} (\varphi\beta)^j \Lambda_{t,t+j} \times \left\{ \frac{P_{H,t}(f)}{P_{t+j}} \mathrm{Y}_{H,t+j}(f) + \frac{S^{us}_{t+j} \widetilde{P}_{H,t}(f)}{P_{t+j}} \left[Y^{*}_{H,t+j}(f) + Y^{us}_{H,t+j}(f) \right] \right.$$
$$\left. - (1-\eta) MC_{t+j} \left[Y_{H,t+j}(f) + Y^{*}_{H,t+j}(f) + Y^{us}_{H,t+j}(f) \right] \right\}, \quad \text{(E.3)}$$

subject to the endogenous discount factor $\Lambda_{t,t+j}$, the consumer price level P_t, real marginal costs measured in terms of the aggregate consumption good, MC_t, a fiscal subsidy to all factors of production η, Home, Foreign and US demand for goods of firm f given by $Y_{H,t}(f) = C_{H,t}(f) + M_{H,t}(f)$, $Y^{*}_{H,t}(f) = C^{*}_{H,t}(f) + M^{*}_{H,t}(f)$ and $Y^{us}_{H,t}(f) = C^{us}_{H,t}(f) + M^{us}_{H,t}(f)$, respectively, as well as the nominal exchange rate vis-à-vis the US dollar, S^{us}_t.

The case of DCP entails several conceptual complications. First, in order to ensure comparability of the case of DCP with those of PCP and LCP, we need to base the analysis on the same measure of GVCP. Specifically, in order to be able to measure Home GVCP by the VAX ratio in Equation (9) also in the three-country model, we assume that Home and Foreign trade

[21] The setting shares features with the models of Casas et al. (2017) as well as Boz et al. (2017). However, again for simplicity, we do not assume strategic complementarities in price setting that give rise to variable mark-ups.

[22] Domestically consumed goods are still priced in the local currency. US firms price all their goods in US dollar.

volumes with the US are close to zero. While this is counterfactual empirically, it facilitates grasping the intuition underlying the mechanisms under DCP, similarly to the assumption of Home being small maintained in part above. Second, under DCP we need to make an assumption regarding the behaviour of the exchange rate of the US dollar when the bilateral exchange rate between Home and Foreign changes. Intuitively, under DCP, if the Home currency appreciates only against the Foreign currency but not against the US dollar — i.e. a scenario with a multilateral depreciation of the Foreign currency — Home-currency Home import prices do not change contemporaneously, as prices of Home imports from Foreign are sticky in US dollar. In contrast, Foreign-currency Foreign import prices rise because of the multilateral depreciation of the Foreign currency and because prices of Foreign imports from Home are sticky in US dollar. If the Home currency instead appreciates multilaterally — that is including against the US dollar — Home-currency Home import prices fall, while Foreign-currency Foreign import prices are unchanged. Hence, under DCP the mechanisms differ depending on the scenario specification in terms of the correlation of the US dollar exchange rate with the exchange rate between Home and Foreign.

Against this background, we derive structural ERPT under DCP for two scenarios: (1) The bilateral exchange rate between Home and Foreign moves one to one with the Foreign currency exchange rate against the US dollar, reflecting a scenario of a multilateral exchange rate change of the Foreign currency; (2) the bilateral exchange rate between Home and Foreign moves one to one with the Home currency exchange rate against the US dollar, reflecting a scenario of a multilateral exchange rate change of the Home currency.

Ignoring lag and lead terms, the NK Phillips curves for Home-produced Foreign-consumed goods as well as Foreign-produced Home-consumed goods are described by

$$\hat{p}^*_{H,t} = \hat{p}^*_{H,USD,t} + \hat{s}^{*USD}_t = ... + \frac{\kappa}{1+\beta+\kappa} n\hat{m}c_t - \frac{\kappa}{1+\beta+\kappa}(\hat{s}^{USD}_t) + \hat{s}^{*USD}_t,$$

$$\hat{p}_{F,t} = \hat{p}_{F,USD,t} + \hat{s}^{USD}_t = ... + \frac{\kappa^*}{1+\beta^*+\kappa^*} n\hat{m}c^*_t + \frac{\kappa^*}{1+\beta^*+\kappa^*}(-\hat{s}^{*USD}_t) + \hat{s}^{USD}_t.$$

Substituting the expressions for nominal marginal costs from above (see Section D.2) gives the dynamics of Foreign import prices in local-currency

$$\hat{p}^*_{H,t} \left\{ 1 - \frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} \frac{\kappa^*(1-\widetilde{\alpha}^*)\omega^*}{(1+\beta^*)+\kappa^*(1-(1-\widetilde{\alpha}^*)(1-\omega^*))} \right\} =$$
$$= ... + \frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} \left[\frac{\kappa^*}{1+\beta^*+\kappa^*}(-\hat{s}^{*USD}_t) + \hat{s}^{USD}_t \right] - \frac{\kappa}{1+\beta+\kappa}(\hat{s}^{USD}_t) + \hat{s}^{*USD}_t.$$

DCP (1) (US third country, Foreign currency appreciates versus all currencies)

Assuming $\hat{s}_t^{USD} = 0$ and $\hat{s}_t^{*USD} = -\hat{s}_t$ implies that Foreign ERPT to local-currency import prices follows

$$\hat{p}^*_{H,t}\Omega_{sticky} = ... + \frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))}\left[\frac{\kappa^*}{1+\beta^*+\kappa^*}\hat{s}_t\right] - \hat{s}_t,$$

$$ERPT^{m*} = (-1) * \Omega^{-1}_{sticky}\left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))}\frac{\kappa^*}{1+\beta^*+\kappa^*} - 1\right]. \tag{E.4}$$

Accordingly, Home ERPT to local-currency export prices is given by

$$ERPT^{x} = \Omega^{-1}_{sticky}\left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))}\frac{\kappa^*}{1+\beta^*+\kappa^*} - 1\right] + 1. \tag{E.5}$$

As Figure 2 shows, for both secenarios the effect of GVCP on ERPT to import and export prices under DCP is similar to the PCP and LCP cases. In order to facilitate grasping the intuition underlying the mechanisms we again consider, the polar case in which Home is small relative to Foreign ($n_H \to 0$, $n_F >> 0$). In scenario (1), the multilateral depreciation of the Foreign currency produces an increase in Foreign-currency Foreign export prices — as it would be the case if Foreign exporters operated under LCP — and a rise in mark-ups. In order to stabilise mark-ups, those exporters in Foreign that can adjust reduce their Foreign-currency export prices, again similar to the case of LCP. The reduction in Foreign-currency export prices in Foreign implies a fall in Home-currency import prices in Home. As a result, Home marginal costs fall, which induces those firms that can adjust to decrease their Home-currency export prices. Importantly, this effect is stronger the larger the share of imported intermediate inputs used in Home production, i.e. the stronger Home GVCP. In sum, the positive relationship between ERPT to export prices in Home and Home GVCP documented for the case of flexible prices, PCP and LCP also obtains under DCP scenario (1). Similarly, also the negative relationship between ERPT to import prices in Foreign and Home GVCP also obtains under DCP scenario (1). In particular, as the Home-US dollar exchange rate does not change, the decrease of Home-currency export prices in Home discussed above partially offsets the rise in Foreign-currency import prices in Foreign implied by the depreciation of the Foreign currency against the US dollar. Importantly, this effect is stronger the larger the share of imported intermediate goods used in Home production, i.e. the stronger Home GVCP.

DCP (2) (US third country, Home currency appreciates versus all currencies)

Under the assumption of $\hat{s}_t^{USD} = s_t$ and $\hat{s}_t^{*USD} = 0$, Foreign ERPT to local-currency import prices is

$$ERPT^{m*} = (-1) * \Omega_{sticky}^{-1} \left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - \frac{\kappa}{1+\beta+\kappa} \right]. \tag{E.6}$$

Home ERPT to local currency export prices is given by

$$ERPT^{x} = \Omega_{sticky}^{-1} \left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - \frac{\kappa}{1+\beta+\kappa} \right] + 1. \tag{E.7}$$

In DCP scenario (2), again similar to the case of LCP, the multilateral appreciation of the Home currency implies a fall in Home-currency export prices in Home and hence mark-ups, which induces those firms that can adjust to raise Home-currency export prices. However, to the extent that Home uses imported intermediates from Foreign, Home marginal costs fall, which reduces the need to raise Home-currency export prices in order to stabilise mark-ups. Hence, stronger Home GVCP is associated with higher ERPT to Home-currency export prices in Home also under DCP scenario (2). Similarly, also the negative relationship between ERPT to import prices in Foreign and Home GVCP documented for the cases of flexible prices, PCP and LCP also obtains under DCP scenario (2). In particular, since the bilateral exchange rate between the Foreign currency and the US dollar is unchanged, Foreign-currency import prices in Foreign only rise to the extent that Home exporters increase Home-currency and hence US dollar export prices. As discussed above, Home-currency export prices in Home are raised less the stronger Home GVCP. Hence, ERPT to Foreign-currency import prices in Foreign is lower the stronger Home GVCP.

E.3 PCP/LCP (two-country case and Foreign issues a dominant currency): Home operates under LCP, Foreign under PCP

Under Home LCP we have

$$\hat{p}_{H,t}^{*} = ... + \frac{\kappa}{1+\beta+\kappa} n\hat{m}c_t - \frac{\kappa}{1+\beta+\kappa} \hat{s}_t.$$

Foreign PCP implies

$$\hat{p}_{F,t} = ... + \frac{\kappa^*}{1+\beta^*+\kappa^*} n\hat{m}c_t^* + \hat{s}_t.$$

Plugging in nominal marginal cost from above we get

$$ERPT^{m*} = (-1) * \Omega_{sticky}^{-1} \times \left[\frac{\kappa(1-\widetilde{\alpha})\omega}{(1+\beta)+\kappa(1-(1-\widetilde{\alpha})(1-\omega))} - \frac{\kappa}{1+\beta+\kappa} \right], \tag{E.8}$$

which results in the same ERPT relations as in the DCP (2) case.

The predictions from the model regarding the relationship between ERPT and GVCP are also unchanged when assuming that one economy is subject to PCP while the other economy is subject to LCP. This configuration — at best, see for example Table 1 in Gopinath et al. (2010) — only applies to trade between the US and the rest of the world but not to trade between economies in the rest of the world.

Acknowledgements

We would like to thank Pol Antràs, Richard Baldwin, Peter Egger, Andrea Ferrero, Gernot Müller, Alexander Rodnyansky, Cédric Tille, seminar participants at the Bundesbank and the ECB, as well as participants at the 2017 Computing in Economics and Finance Conference, the 2017 Annual Congress of the Verein für Socialpolitik, the 2018 Annual Meeting of the European Economic Association, the 2018 UC Santa Barbara LAEF conference on "Trade in Dynamic Stochastic General Equilibrium Models", the 11th FIW International Economics Conference, the 2018 Annual International Conference on Macroeconomic Analysis and International Finance, the University of Lille workshop "International finance: do exchange rates still matter?", and the 2019 Annual Conference of the International Association for Applied Econometrics for useful comments. We especially thank Romain Rancière, James Lothian, and Jérôme Héricourt for discussing the paper. Supported by funds of the Oesterreichische Nationalbank (Oesterreichische Nationalbank, Anniversary Fund, project number: 15979). The views expressed in the paper are those of the authors and do not necessarily reflect those of the ECB or the Deutsche Bundesbank.

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PDF ISBN 978-92-899-3896-9 ISSN 1725-2806 doi:10.2866/621932 QB-AR-19-108-EN-N