Estimating the elasticity of consumer prices to the exchange rate: an accounting approach *

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Abstract

We analyze the elasticity of the household consumption expenditure (HCE) deflator to the exchange rate, using world input-output tables (WIOTs) from 1995 to 2019. In line with the existing literature, we find a modest output-weighted elasticity of around 0.1. This elasticity is stable over time but heterogeneous across countries, ranging from 0.05 to 0.22. Such heterogeneity mainly reflects differences in the foreign product content of consumption and intermediate products. Direct effects through imported consumption and intermediate products entering domestic production explain most of the transmission of an exchange rate appreciation to domestic prices. By contrast, indirect effects linked to participation in global value chains play a limited role. Our results are robust to using four different WIOTs datasets. As WIOTs are data-demanding and available with a lag of several years, we extrapolate a reliable year- and country-specific estimate of the HCE deflator elasticity from 2015 onwards, using trade data and GDP statistics.

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Introduction

Over the past two decades, the rise of global value chains has led to a greater use of input-output tables to study international linkages. In this paper, we analyze which countries are most vulnerable to cost-push inflation using world input-output tables (WIOTs hereinafter). We also document the heterogeneous sensitivity of consumer prices to exchange rate variations across countries, reflecting differences in the foreign product content of consumption and intermediate products. Understanding the influence of exchange rate variations on inflation is indeed critically important for measuring the extent of expenditure switching that follows exchange rate variations, which, in turn, has an impact on real activity. To shed light on these mechanisms, we analyze the elasticity of the household consumption expenditure (HCE) deflator to the exchange rate.

We perform an accounting exercise based on information contained in WIOTs, by way of large matrices inversions. We use several datasets covering most advanced and emerging economies from 1995 to 2019. Our accounting approach helps identify which countries and sectors are under pressure to adjust their prices following an exchange rate variation.

Our paper builds on two strands of literature. A first strand of literature documents the exchange rate pass-through to domestic prices (ERPT hereinafter). The pass-through depends, among other things, on trade openness, integration in international production chains, firms' pricing strategies and the currency of invoicing for trade. In addition to these structural features, some authors analyze the underlying shocks that cause exchange rate fluctuations (eg. Forbes et al. (2018)), as well as the role of monetary policy (see for instance Ha et al. (2020), who show that the transmission is lower in countries that combine flexible exchange rate regimes and credible inflation targets). Another strand of literature sheds light on the transmission of shocks across countries through input-output linkages (I-O hereinafter). The trade in value-added analysis reconciles international trade statistics with national I-O tables, thus allowing to extend Leontief's analysis (Leontief, 1951) to an international context. Most of this literature focuses on the transmission of production shocks through input-output linkages (e.g. Eaton et al. (2016); Johnson (2014)). By contrast, we use WIOTs to analyze cost-push inflation (as do Aydoğuş et al. (2018)). Our paper contributes to both strands of literature: our computations are based on input-output matrices, while our results are comparable with estimations from the

ERPT literature.

We make several assumptions to simplify our computations. First, we assume a full exchange rate pass-through (ERPT) to import prices. Hence, we do not consider the fact that the pass-through might be incomplete, as suggested by a large body of literature (see Ortega and Osbat (2020) for a literature review of recent studies relying on various methodologies such as VAR, dynamic simultaneous equations, Bayesian VAR or local projections). For example, Özyurt (2016) shows that in the euro area, the pass-through is partial and has declined in the 2000s. The lowest degree of pass-through is found in Germany, most likely reflecting the large size of the German economy and the high share of local currency pricing. As a result, our estimates provide an upper bound of the HCE deflator elasticity compared to results from the ERPT literature. Second, we suppose that all invoicing occurs in the currency of the producing country. The invoicing decision is an active channel through which producers adjust their prices in relation to their own market power and to local competitive pressures. Prices fixed in the local currency are sticky in the currency of the destination market and irresponsive to changes in the bilateral exchange rate between the local currency and the currency of the producer. By contrast, prices fixed in the producer's or dominant currency have a higher ERPT. Contrary to our hypothesis, a large body of empirical literature suggests that the vast majority of trade is invoiced in a small number of 'dominant currencies', with the U.S. dollar playing a major role. The 'dominant currency paradigm' (Gopinath et al., 2020) implies that for non-U.S. countries, the ERPT into import prices (in home currency) should be high and driven by the U.S. dollar exchange rate as opposed to the bilateral exchange rate, whereas for the U.S. the pass-through into import prices should be low. Gopinath et al. (2007) also show that there is a large difference in the ERPT of the average good priced in dollars (25%) versus non-dollars (95%). Hence, using alternative pricing assumptions would entail lower estimates of the elasticity of consumer prices to the exchange rate.[1]

Despite these simplifying assumptions, our estimates provide an accounting-based gauge of how large the elasticity of consumer prices to the exchange rate could be, considering direct and indirect import content in consumption and global value chain linkages. Furthermore, our results

[1] Note that the upward bias stemming from our simplifying assumptions is unlikely to be constant among countries. The magnitude of the bias depends on the size of the economy. In particular, in large and attractive markets, competitive pressures may push producers to adopt local currency pricing strategies. Hence, exporting firms may adapt their mark-ups depending on the destination market to offset exchange rate movements. As a result, the upward bias in our estimated elasticities might be more pronounced for the largest and most attractive markets represented in our sample.

broadly concur with the recent literature. For instance, Colavecchio and Rubene (2020), using local projection techniques, find an ERPT to consumer prices ranging from 0.07 to 0.23 in the euro area. Our results also concur with those in Aydoğuş et al. (2018), which examine the pass-through to the domestic price level through an input–output model for 26 countries, using I-O tables. The estimated elasticity of the CPI to the exchange rate ranges from 0.07 for the US to 0.34 for Ireland, with a simple average of 0.18.

We make several contributions to the literature.

First, we analyze the evolution of the elasticity of the HCE deflator to the exchange rate. We document differences across countries. We pay particular attention to the heterogeneity observed in the euro area, reflecting different degrees of openness to trade.

Second, we analyze the impact on the domestic economy of variations in the currencies of trading partners. We show that countries are affected in proportion to their trading links with the country whose currency appreciates. For illustration, we estimate the accounting impact of an appreciation of the US dollar.

Third, building on sectoral data, we examine which sectors experience higher spillovers from an appreciation of the national currency. We focus on the main components of the HCE deflator, i.e., manufacturing goods, services, food and energy. We analyze the contribution of these different products to the HCE deflator's elasticity and document cross-country heterogeneity in the elasticity.

Fourth, we look into the determinants of the HCE deflator elasticity and the role of global value chains in the transmission of an exchange rate appreciation. We identify the main channels through which the exchange rate impacts the HCE deflator when production processes are global. We find that the main transmission channels are: *i)* the prices of imported final goods sold directly to domestic consumers and *ii)* the prices of imported inputs entering domestic production. These two channels explain three-quarters of the transmission of an appreciation in the exchange rate to domestic prices. By contrast, other channels reflecting the impact of global value chains (such as the price of exported inputs feeding through imported foreign production) play a more limited role, with marked cross-country heterogeneity. Hence, only one-fourth of the elasticity of the HCE deflator to the exchange rate is attributable to participation in global value chains.

Fifth, we show that a precise assessment of the HCE deflator's elasticity to the exchange rate can be estimated for recent years without resorting to WIOTs. The construction of WIOTs is data-demanding, and they are typically released with a lag of several years. As a result, WIOTs are not available for the most recent years. For instance, the latest WIOD dataset dates back to 2014. Although the MRIO dataset covers most recent years, it suffers from data quality issues from 2018 onwards. To address the data gap in WIOTs, we extrapolate the HCE deflator elasticity from 2015 onwards using up-to-date GDP statistics and trade data on consumption and intermediates. We obtain a reliable estimate of the HCE deflator elasticity up to 2019. Most of the existing literature provides an average elasticity computed over a sample of several years. By contrast, our proxies based on up-to-date trade and GDP statistics allow us to track the evolution of the HCE deflator elasticity in a more up-to-date way, from one year to the next.

Last but not least, we use several WIOTs for the sake of robustness (i.e., WIOD, two distinct releases of the OECD TiVA database, and the MRIO database). To the best of our knowledge, such a comprehensive robustness check is seldom performed in the existing literature. Overall, we show that results from different WIOTs converge.

The rest of the paper is organized as follows. In section 1, we review the data sources and outline the main differences between the various WIOTs. In section 2, we present our method. In section 3, we estimate the elasticity of the HCE deflator to the exchange rate up to 2019 and analyze its determinants. In section 4, we use up-to-date GDP and trade data to estimate the elasticity of the HCE deflator for the most recent years.

1 Data

In this paper, we perform an accounting exercise based on information contained in WIOTs, by way of large matrices inversion. WIOTs are an extension of national input-output tables.

National input-output tables measure the relationships between the producers of goods and services (including imports) within an economy and the users of these goods and services (including exports). National tables specify, in line, for each industry, the use of their product as intermediate or final use. In a national table, final use includes exports alongside domestic final uses, whereas exports are not a final use in world input-output tables. WIOTs show which foreign industry produces a good for a specific final use, and which foreign industry or final user uses the exports of a given country.

Aggregating national input-output tables into world input-output tables is challenging for a number of reasons. National input-output tables vary widely in terms of detail and scope, and are therefore not fully consistent. Furthermore, the availability of year-specific national input-output tables is limited, especially for developing economies.

In this paper, we use several multi-year WIOTs for the sake of robustness: *i)* the World Input Output Database (WIOD), *ii)* the multi-regional input-output tables (MRIO) developed by the Asian Development Bank (ADB) and *iii)* the Trade in Value Added Database (TiVA) from the OECD-ICIO.

1.1 The World Input Output Database (WIOD)

The World Input Output Database (WIOD) is hosted and updated by the University of Groningen (Netherlands).[2] The WIOD contains time series of inter-country input-output tables from 2000 to 2014. It provides WIOTs that reconcile national input-output tables (or supply-use tables) with bilateral trade statistics. The WIOD covers 43 countries (of which 30 European economies, see Table 1) accounting for 85% of global GDP. It contains information for 56 industries (see Online Appendix A) and provides annual WIOTs expressed in U.S. dollars at basic prices.[3]

Europe	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom
North America	Canada, United States
Latin America	Brazil, Mexico
Asia-Pacific	Australia, China, India, Indonesia, Japan, Korea, Taiwan
Other	Russia, Turkey

Tab. 1: **Geographical coverage of WIOD**

1.2 The Asian Development Bank's MRIO database

The Asian Development Bank's MRIO database is an extension of WIOD for 2000 and 2007-2019. As the WIOD covers a limited number of Asian economies, the Asian Development Bank has augmented it with details for nineteen additional Asian economies.[4] This wider geographical coverage comes at the price of a lower industrial coverage (35 vs 56 sectors in WIOD). The

[2] It benefits from the financial support of the European Commission.

[3] Market exchange rates were used for currency conversion (Timmer et al., 2015).

[4] The MRIO database includes the following additional economies: Bangladesh, Bhutan, Brunei Darussalam, Cambodia, Fiji, Hong Kong, Kazakhstan, Kyrgyz Republic, Lao People's Democratic Republic, Malaysia, Maldives, Mongolia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Viet Nam.

conceptual framework of the MRIO database (and hence the methods used in the construction of the tables) are similar to those of WIOD. Its main advantage is to be updated up to 2019.

1.3 The Trade in Value Added (TiVA) database

The Trade in Value Added (TiVA) database is compiled by the OECD. It builds on the OECD harmonised country-level input-output tables to provide matrices of inter-industrial flows of goods and services in current prices (U.S. dollars).
We use two versions of TiVA (see OECD (2018) on the differences between the two datasets). The 2016 edition of the TiVA database (third revision) includes 64 economies covering the OECD, the EU, the G20 and most East and South-east Asian economies, a selection of South American countries and the Rest of the world (see Table 2). It covers 34 sectors, among which 16 manufacturing and 14 services sectors. The third revision of TiVA covers the period 1995-2011 and is based on the 1993 system of national accounts. The fourth revision, released in 2018, includes 65 economies (see Table 2) and 36 sectors and covers the 2005-2015 period. Just like WIOD and MRIO, the fourth revision of TiVA is based on the 2008 system of national accounts.

Europe	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom
North America	Canada, United States
Latin America	Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico (differentiating between three (Rev. 3) or two (Rev. 4) Mexico), Peru
Asia-Pacific	Australia, Cambodia, China (differentiating between four (Rev. 3) or three (Rev. 4) China), Hong Kong SAR, India, Indonesia, Japan, Khazakhstan (in Rev. 4), Korea, Malaysia, New Zealand, Philippines, Singapore, Taiwan, Thailand, Viet Nam
Other	Brunei, Israel, Morocco, Russia, Saudi Arabia, South Africa, Tunisia, Turkey

Tab. 2: **Geographical coverage of TiVA revisions 3 (2016) and 4 (2018)**

1.4 Comparison of the different databases

All four databases are constructed using similar assumptions (OECD (2018); OECD and WTO (2011); Timmer et al. (2015)). For example, all start with the construction of harmonised country-specific supply-use tables (SUTs) that are then transformed into world input-output tables. All databases use the "import proportionality assumption" to allocate specific bilateral imports to using industries. National input-output statistics provide how much of each product a given sector uses for intermediary consumption and investment. However, the breakdown of these into domestic and imported product is not available. Hence, the construction of world input-output tables requires allocating imports to using industries.

The import proportionality assumption assumes that the proportion of intermediates that an industry purchases from abroad is equal to the ratio of imports of intermediates to the total domestic demand of intermediates in that product. However, this assumption can be misleading. Feenstra and Jensen (2012) find that shares of imported materials differ substantially across U.S. industries. Based on Asian input-output tables, Puzzello (2012) finds that the proportionality assumption understates the use of foreign intermediate inputs. All databases, however, rely on the BEC (Broad Economic Categories) classification to map detailed six-digit products into intermediate use, final consumption and investment (Dietzenbacher et al., 2013).

One explicit difference between the databases is that WIOD and MRIO assume that the input mix is independent from the destination market. The TiVA databases do not rely on this assumption for two countries (Mexico and China). Instead, the TiVA databases use different input-output tables for the exporting, import processing and domestic-market oriented sectors of these countries. Despite this difference, we obtain similar results with TiVA, WIOD and MRIO, which probably reflects the fact that we do not focus on Mexico and China.

Another difference relates to the method for harmonising national data and trade statistics. WIOD and MRIO rely on the shares of imported inputs provided by national account, contrary to TiVA. As a result, TiVA is closer to international trade statistics than WIOD. This explains why the share of imported inputs is smaller in TiVA for some countries. All computations in the paper have been conducted with the four databases. For ease of exposition, we use the WIOD as a baseline, since it covers the largest number of industries.

2 An accounting approach to computing the HCE deflator elasticity

2.1 Extending Leontief's analysis to an international context

The Leontief's production model analyzes the impact of a demand shock in a closed economy (Leontief, 1951) and is broadly used in multi-sector, single-country macroeconomic models. The trade in value-added analysis reconciles international trade statistics with national I-O tables, thus extending Leontief's analysis to an international context. Supply-driven price models have well-documented limitations (Folloni and Miglierina, 1994) and rely on a number of simplifying assumptions.[5] They nevertheless provide a measure of the vulnerability of each sector to price or productivity shocks. Hence, though unrealistic, these models are useful for identifying which countries and sectors are under pressure to adjust their prices when subject to exogenous cost shocks.

Leontief's production model has a dual: the cost-push price model, which helps to analyze the consequences of changes in production prices. Based on initial work from the OFCE (Observatoire Français des Conjonctures Économiques) outlined in Cochard et al. (2016), we have developed the PIWIM model (Push-cost Inflation through World Input-output Matrices). We present the main features of the PIWIM model below.

2.2 Setup of the model

To identify which countries are most affected by a change in prices through value-added and vertical international trade flows, we need a large structural matrix that integrates input flows between sectors, both within each country and between countries. This matrix traces the sectoral and geographical origin of inputs.

The standard I-O model relies on input-output tables registering transactions of goods and services (domestic or imported) at current prices. The I-O tables describe the sale and purchase relationships between producers and consumers within an economy. Each column indicates, for each industry j, the intermediate consumption of goods and services from the various sectors.

By extension, a "world" I-O table (WIOT) describes the sale and purchase relationships between producers and consumers in the whole world, differentiating between sectors in different countries. The WIOT has, on its diagonal, country blocks recording flows of domestic transactions of intermediate goods and services between domestic industries. The "bilateral" blocks outside of the diagonal represent international flows of intermediate goods and services via bilateral sectoral exports and imports.

Traditionnaly, WIOTs are interpreted in a Leontief framework using Leontief production functions to analyze the evolution of quantities in the economy. Here, we assume a Cobb-Douglas production function: the technical coefficients correspond to the share of each input in total costs. We derive a price equation, following De Soyres et al. (2018).

We define N as the product of the number of countries (I) and the number of sectors (J), $\mathcal{A}$

[5] In particular, firms' margins are assumed to be fixed; prices only adjust to absorb cost changes; production techniques are fixed during successive production cycles; inputs substitution caused by change in relative prices is not accounted for.

the matrix of technical input coefficients of dimension (N, N), and Y the gross output vector of dimension $(1, N)$.

In each sector of each country, a representative firm uses domestic production factors (V) and domestic and imported intermediates m according to a Cobb-Douglas technology:

$$Y_n = V_n^{\gamma_n} \times \prod_{n'=1}^{n'=N} {m_{n,n'}}^{a_{n,n'}} \text{ with } \gamma_n + \sum_{n'=1}^{n'=N} a_{n,n'} = 1$$

Where γ_n is the share of domestic production factors, $a_{n,n'}$ the share of output from (country,sector) n' in the total production of (country,sector) n.

Assuming perfectly competitive firms and prices set at the marginal cost, standard cost minimisation for each country leads to the following pricing system:

$$p_n = x_n \times w_n^{\gamma_n} \times \prod_{n'=1}^{n'=N} p_{n'}^{a_{n,n'}}, \forall n$$

With w_n the unit income of domestic production factors and x_n a constant depending only on parameters:

$$x_n = \gamma_n^{-\gamma_n} \times \prod_{n'=1}^{n'=N} a_{n,n'}^{-a_{n,n'}}$$

Using logs, we have:

$$log(p_n) = log(x_n) + \gamma_n log(w_n) + \sum_{n'=1}^{n'=N} a_{n,n'}.log(p_{n'}), \forall n$$

Define P the vector of prices and Z a vector of $log(x_n) + \gamma_n.log(w_n)$, both of dimension $(1, N)$:

$$log(P) = Z + log(P)\mathcal{A} \tag{1}$$

2.3 Accounting impact of an exchange rate variation on domestic prices

In this section, we focus on the impact of an exchange rate appreciation on consumer prices in the country whose currency's value is changing (country A by convention).[6] We also estimate the inflationary impact on countries that directly and indirectly, through third countries linkages, consume inputs from country A. Hence, we will also analyze the impact of an appreciation of the US dollar. The appreciation of the currency of country A leads to a fall in the national currency price of country A's imports, while the foreign-currency price of its exports increases.

Suppose a world with two countries A and B, each having its own national currency, and using a third currency for international transactions, the dollar. Following a 5% appreciation of the currency of country A against the two other currencies, the prices of country A expressed in dollars increase by 5% compared to those of country B expressed in dollars. Country B pays more for its imports of inputs, in dollars as well as in national currency, since its exchange rate against the dollar has not changed. Conversely, the price of imported inputs in country A in dollars increase since the prices of country B have increased to accomodate more expensive inputs from country A. Prices in country A in national currency decline however, as this effect is more than counter-balanced by the appreciation of country A's national currency. This has an impact on consumer prices expressed in national currency in country A.[7]

The change in the prices of imported goods is therefore transmitted to all domestic prices, both directly and through inter-industry linkages. These upward (downward) movements for country B (country A) affect all input prices in both countries.

The effects of the change in prices spread over multiple simultaneous production cycles. The overall impact of the exchange rate appreciation in dollar terms is equal, for the shocked country A, to the decline in consumer prices directly due to the exchange rate fluctuation, plus direct and indirect decreases (via inter-industry linkages in the country), in national currency and then converted back into dollar terms, in the prices of inputs imported from B and disseminated to all

[6] See Online appendix B for details on the computation of the impact of a change in input prices using an I-O model on prices.

[7] For the sake of simplicity, we make the strong assumption that producers completely pass the exchange rate appreciation on their production prices. We do not consider other relevant determinants of the exchange rate pass-through. For instance, pricing-to-market strategies of exporters aiming to defend their market shares would imply a lower exchange rate pass-through. Similarly, settlement and invoicing of imports in the domestic currency is another factor likely to weaken the elasticity of domestic prices to exchange rate movements. Assuming that only 60% of invoices in the euro area goods trade are denominated in foreign currency (see Ortega and Osbat (2020)) would entail lower elasticity values. To anticipate on our results (see Figure 9), reducing the exchange rate pass-through on consumption goods would entail lower elasticity values than reducing the pass-through on inputs. Our estimates thus provide an upper bound of the HCE deflator elasticity.

branches. The overall impact on prices in dollar terms in country A is therefore lower than the initial exchange rate variation, as national currency prices are also affected. For country B, the final impact is equal to the cumulative direct and indirect effects of the higher prices of imported inputs.

In a global economy composed of I countries, each with J sectors,[8] the appreciation of a country's currency i against all other currencies translates into a rise in country i's prices in dollars. The dollar price of each sector will vary in percentage (approximated as log point assuming that the exchange rate variation is small enough) by: $c^i_\$$ for sectors in the shock-stricken country i and 0 in other countries.

Hence, for each sector j in country i (see notation table):

$$\Delta^0 log(p_{\$ij}) = log(p^1_{\$ij}) - log(p^0_{\$ij}) = c_{\$ij} = c^i_\$$$

And for each sector j in country $k(k \neq i)$,

$$\Delta^0 log(p_{\$kj}) = log(p^1_{\$kj}) - log(p^0_{\$kj}) = c_{\$kj} = 0$$

The appreciation affects producers through changes in relative prices between countries and, therefore, through changes in input prices traded between the shock-stricken country i and other countries.

Consider first the direct impact on other countries of the rise in imported input prices from shocked country i. For any sector l of a country k $(k \neq i)$, the increase in producer prices depends directly on the quantity of inputs imported from the shock-stricken country i, weighted by the variation in level of the price of inputs in dollars (i. e. the exchange rate variation). If $a_{kl,ij}$ is the share of inputs from the country i's sector j needed in the production of country's k sector l, we have :

$$\Delta^1 log(p_{\$kl}) = c^i_\$.a_{kl,i1} + \ldots + c^i_\$.a_{kl,ij} + \ldots + c^i_\$.a_{kl,iJ} = \sum_{j=1}^{J} c^i_\$.a_{kl,ij} = c^i_\$.\sum_{j=1}^{J} a_{kl,ij} \qquad (2)$$

[8] Online appendix C explores the two-country, one-sector case and contrasts the effect of an exchange rate variation and the effect of a price variation

For the shocked country, an appreciation of the currency has a disinflationary effect. In national currency, the prices of imported inputs fall in each sector by $c^i = -\frac{c^i_\$}{1+c^i_\$}$, or by $-\frac{10}{1.1}\%$ with $c^i_\$ = 10\%$.

We approximate these changes by their log point equivalent.[9] This decline then spreads to all domestic-input using sectors. In sector j of the shocked country i, this fall amounts in national currency to:

$$\Delta^1 log(p_{ij}) = \sum_{l=1}^{l=J} c^i.a_{ij,1l} + \ldots + \sum_{l=1}^{l=J} c^i.a_{ij,kl} + \sum_{l=1}^{l=J} c^i.a_{ij,Il} = \left(-\frac{c^i_\$}{1+c^i_\$}\right) . \sum_{\substack{k=1 \\ k \neq i}}^{k=I} \left[\sum_{l=1}^{l=J} a_{ij,kl}\right]$$

This change can be converted into dollars:

$$\Delta^1 log(p_{\$ij}) = \left(1 + c^i_\$\right) . \left(-\frac{c^i_\$}{1+c^i_\$}\right) \sum_{\substack{k=1 \\ k \neq i}}^{k=I} \left[\sum_{l=1}^{l=J} a_{ij,kl}\right] \tag{3}$$

This yields the first step impact of the exchange rate variation on all input prices of all countries. To express this in matrix notation, we define two matrices that build on the world input-output matrix $\mathcal{A}$ defined in 2.2 : $\mathcal{B}^i$ and $\tilde{\mathcal{B}^i}$. These two matrices retain only the first-step effects of the exchange rate variation on the price of goods and services imported by the shocked country i and the first-step effects of the exchange rate variation on the price of goods and services imported by the rest of the world from country i. Compared to $\mathcal{A}$, we "close off" the links between a change in domestic input prices and the price of goods as well as the link between non-shocked input prices and the price of goods in a non-shocked country (see the notation table and infra)

Let us first consider the impact of the exchange rate variation from the perspective of countries that import inputs from country i.

Let $C^i_\$$ be the vector of log points changes in dollar prices following the appreciation of the

[9] We could have used the log point approximation earlier and write that $c^i = -c^i_\$$ with nearly the same results for small exchange rate variations.

currency of country i against all other currencies. Hence,

$$C_{\$}^{i} = \left(0 \dots 0 \dots c_{\$ij} \dots c_{\$ik} \dots 0 \dots 0\right)$$

with $c_{\$ij} = c_{\$ik} = c_{\$}^{i}$ for all sectors j and k in the shocked country i.

Building on Equation 2, the direct impact of the exchange rate variation on the other countries corresponds to the product of the shock vector $C_{\$}^{i}$ and a matrix $\mathcal{B}^{i}$. $\mathcal{B}^{i}$ builds on the large matrix $\mathcal{A}$ of technical coefficients, but only keeps the coefficients of each country's sectoral inputs imported from the shocked country i. The other coefficients are replaced by 0, including those of the block of country i concerning the domestic inputs of country i. The first-step impact of the appreciation of a currency against the dollar on the price of inputs in countries that are not impacted by the appreciation is equal to $C_{\$}^{i}\mathcal{B}^{i}$ with

$$C_{\$}^{i}\mathcal{B}^{i} = \left(0 \dots c_{\$}^{i} \dots 0\right) \begin{pmatrix} 0 & \cdots & 0 \\ a_{11,ij} & 0 & a_{IJ,ij} \\ 0 & \cdots & 0 \end{pmatrix} \tag{4}$$

where each $a_{kl,ij}$ element of the line block represents the technical coefficient related to imports of inputs by sector l in country k (with $k \neq i$) from sector j of country i.

Let us now consider the impact of the exchange rate fluctuation from the perspective of the shocked country i.

Define C^{i} the vector of change in prices everywhere expressed in country i's currency.

$$C^{i} = \left(-\frac{c_{\$}^{i}}{1+c_{\$}^{i}}, \dots 0 \dots, -\frac{c_{\$}^{i}}{1+c_{\$}^{i}}\right)$$

From Equation 3, we write the first-step impact for country i of the fall in input prices from the rest of the world. The first-step impact is the product of the shock vector C^{i} and a matrix $\tilde{\mathcal{B}}^{i}$. $\tilde{\mathcal{B}}^{i}$ builds on the large matrix $\mathcal{A}$ of which only the country blocks of those inputs imported by country i from other countries have been retained. The other coefficients are replaced by 0, including those of the block of country i concerning the domestic inputs of country i.

Notation table

- $a_{kl,ij}$: the share of inputs from country i's sector j in the production of country's k sector l.
- $\mathcal{A}$: Matrix of world input-output coefficients.
- $\mathcal{B}^i$: $\mathcal{A}$ including only the country blocks of each country's sectoral inputs imported from country i (excluding domestic inputs in i).
- $\tilde{\mathcal{B}}^i$: $\mathcal{A}$ including only the country blocks of the inputs imported by country i from other countries (excluding domestic inputs in i).
- $c^i_\$$: change in the exchange rate of the currency of country i in dollar. If it appreciates by 10%, $c^i_\$ = 0.1$.
- c^i: impact of the exchange rate variation on the price of non-i goods expressed in the currency of i. $c^i = -\frac{c^i_\$}{1+c^i_\$}$. If $c^i_\$ = 0.1$, $c^i = -0.0909...$
- C^i: vector of log point changes in prices everywhere expressed in country i's currency: $C^i = \left(-\frac{c^i_\$}{1+c^i_\$}, \ldots 0 \ldots, -\frac{c^i_\$}{1+c^i_\$}\right) = (c_i, \ldots 0 \ldots, c_i)$
- $C^i_\$$: vector of log points changes in dollar prices following the appreciation of the currency of country i against all other currencies. $C^i_\$ = \big(0 \ldots 0 \ldots c_{\$ij} \ldots c_{\$ik} \ldots 0 \ldots 0\big)$ with $c_{\$ij} = c_{\$ik} = c^i_\$$
- $\hat{C}^i_\$$: vector of the log point changes in dollar prices of goods and services from country i used as inputs in all other countries. $\hat{C}^i_\$ = \left(0 \ldots \frac{c^i_\$}{1+c^i_\$}, \ldots 0\right)$
- $p_{\$ij}$: price of goods producted by the sector j in country i in dollars (or any international reference currency)

The first-step impact of the appreciation of the country i's currency on the price of its inputs corresponds, in national currency, to $C^i\tilde{\mathcal{B}}^i$ with:

$$C^i\tilde{\mathcal{B}}^i = \left(-\frac{c^i_\$}{1+c^i_\$}, \ldots 0 \ldots, -\frac{c^i_\$}{1+c^i_\$}\right) \begin{pmatrix} 0 & \ldots a_{ij,11} \ldots & 0 \\ 0 & 0 & 0 \\ 0 & \ldots a_{ij,IJ} \ldots & 0 \end{pmatrix} \tag{5}$$

where each $a_{ij,kl}$ element in the column block represents imports of inputs by sector j in country i from sector l of country k. We then convert the direct impact into dollars, by multiplying it by the new value of the national currency in dollars, $\left(1+c^i_\$\right)$. The direct impact of the appreciation of country i's currency on the price of its inputs corresponds, in dollars, to $\tilde{C}^i_\$\tilde{\mathcal{B}}^i$ with:

$$\tilde{C}^i_\$\tilde{\mathcal{B}}^i = \left(1+c^i_\$\right).C^i\tilde{\mathcal{B}}^i = \left(-c^i_\$ \ldots 0 \ldots - c^i_\$\right) \begin{pmatrix} 0 & \ldots a_{ij,11} \ldots & 0 \\ 0 & 0 & 0 \\ 0 & \ldots a_{ij,IJ} \ldots & 0 \end{pmatrix} \tag{6}$$

The first-step effect on the world is therefore the sum of the vectors from equations 4 and 6, i.e. $C^i_\$.\mathcal{B}^i + \tilde{C}^i_\$\tilde{\mathcal{B}}^i$.

The change in input prices then spreads to all sectors in all countries via the global intersectoral exchanges transcribed by the matrix of technical coefficients of the large matrix $\mathcal{A}$. This process will be simultaneously repeated several times, until the effects completely wear off. In the end, the total price effect of the exchange rate variation is equal to the sectoral shock itself, incremented by changes in input prices due to changes in imported input prices (both in the shocked country and in non-shocked countries), and by all changes in prices during the production processes:

$$\begin{aligned} S^i_\$ = \Delta P^i_\$ = C^i_\$ \quad & + \quad \left(C^i_\$.\mathcal{B}^i + \tilde{C}^i_\$\tilde{\mathcal{B}}^i\right) + \left(C^i_\$.\mathcal{B}^i + \tilde{C}^i_\$\tilde{\mathcal{B}}^i\right)\mathcal{A} + \left(C^i_\$.\mathcal{B}^i + \tilde{C}^i_\$\tilde{\mathcal{B}}^i\right)\mathcal{A}^2 \\ & + \quad \ldots + \left(C^i_\$.\mathcal{B}^i + \tilde{C}^i_\$\tilde{\mathcal{B}}^i\right)\mathcal{A}^k + \ldots \end{aligned}$$

$$S^i_\$ = C^i_\$ + \left(C^i_\$.\mathcal{B}^i + \tilde{C}^i_\$\tilde{\mathcal{B}}^i\right) * (I-\mathcal{A})^{-1} \tag{7}$$

With $S^i_\$$ the total impact vector composed of the elements $s^i_{\$kj}$ showing the total impact of a change in the exchange rate of country i on the price of the country k's sector j in international currency expressed in log points. Equation 7 gives the evolution of sectoral prices in international currency. Analysing this vector is the main objet of Cochard et al. (2016), which focuses on the evolution of price-competitiveness.

By contrast, we focus on the effect of an exchange rate variation on consumer prices. Hence, we are interested in the same impact expressed in national currency. To obtain the evolution of the sectoral prices of the shocked country in national currency, we remove the exchange rate variation in international currency, multiply the balance by the scalar of conversion equal to $\frac{1}{1+c^i_\$}$ and add the initial exchange rate variation in national currency.

$$\begin{aligned} S^i &= C^i + \left(\frac{1}{1+c^i_\$}\right) * \left(S^i_\$ - C^i_\$\right) \\ &= C^i + \left(\frac{1}{1+c^i_\$}\right) * \left(C^i_\$.\mathcal{B}^i + \tilde{C}^i_\$\tilde{\mathcal{B}}^i\right) * (I-\mathcal{A})^{-1} \\ &= C^i + \left(\hat{C}^i_\$.\mathcal{B}^i + C^i\tilde{\mathcal{B}}^i\right) * (I-\mathcal{A})^{-1} \end{aligned} \tag{8}$$

Where $\hat{C}^i_\$ = \left(0 \ldots \frac{c^i_\$}{1+c^i_\$}, \ldots 0\right)$ is the increase in dollar prices of goods and services from country i used as inputs in all other countries.

S^i represents the overall impact of an exchange rate variation on prices in each sector of each country expressed in the currency of country i. S^i is expressed in log points. If the variation is small enough, the elements of S^i correspond to the elasticities to the exchange rate of consumer prices in country i.[10]

To convert this vector into the HCE[11] deflator elasticity in country i, $\bar{s}^i$, we use the household consumption shares to compute a weighted average of the elements of S^i. Let HC^i be the vector

[10] We return to this equation and its interpretation in section 4 (see equation 13).

[11] The HCE deflator covers more products and has different sectoral weights than the headline consumer price index (CPI) as the former also encompasses, for example, the rental equivalent of real estate expenditures.

of sectoral shares in country i's household consumption:[12]

$$HC^i = \begin{pmatrix} \frac{hc^i_{11}}{hc^i} \\ \cdots \\ \frac{hc^i_{kj}}{hc^i} \\ \cdots \\ \frac{hc^i_{IJ}}{hc^i} \end{pmatrix}$$

Where hc^i_{kj} corresponds to household consumption in country i of goods and services produced by sector j from country k and hc^i represents the total household consumption of country i.

The elasticity of the HCE deflator of country i to its own exchange rate is $\overline{s_i}^{i,HC}$:

$$\overline{s}_i^{i,HC} = S^i.HC^i = \sum_{\substack{j=1...J \\ k=1...I}} s^i_{kj}.\frac{hc^i_{kj}}{hc^i} \tag{9}$$

where s^i_{kj} is a coefficient of S^i for country i.

3 Accounting impact of an exchange rate variation on consumer prices

We use the model presented in Section 2.3 to analyze the impact of an exchange rate variation on the household consumption expenditure (HCE) deflator.[13]

Following an appreciation of the national currency versus all other currencies, imported inputs and imported consumer goods become cheaper and domestic prices expressed in national currency decrease.

3.1 Heterogeneity across countries

Using the WIOD database, which covers a sample of 43 countries, we find that the HCE deflator elasticity ranges from 0.05 to 0.22 depending on the country (see Figure 1). This heterogeneity reflects different degrees of openness to trade and differences in foreign product content in domestic consumption.

The elasticity is lower for large advanced and developing countries. For instance, we find an

[12] Consumption is at market prices, whereas all WIOTs are at basic prices. To move from one to the other, we make the simplifying assumption that all taxes and subsidies on products are proportional, as is the value-added tax.

[13] We assume that the variation in the nominal exchange rate is small enough to assimilate log and percentage points. Hence, we consider $\overline{s_i}^{i,HC}$ as the HCE deflator elasticity to its own exchange rate.

elasticity of 0.06 in 2014 for the US. Within the euro area, the elasticity of the HCE deflator differs substantially, ranging from 0.07 in Italy to 0.18 in Ireland, a small open economy with a large traded sector and a large share of trade outside the euro area. For larger countries (France, Germany, Italy and Spain) and countries whose trade is concentrated with euro area partners (such as Portugal and Greece), the elasticity is close to 0.10, reflecting a lower degree of openness to trade. The elasticity is twice higher for small open economies like Luxembourg, Malta, Slovakia and Ireland.

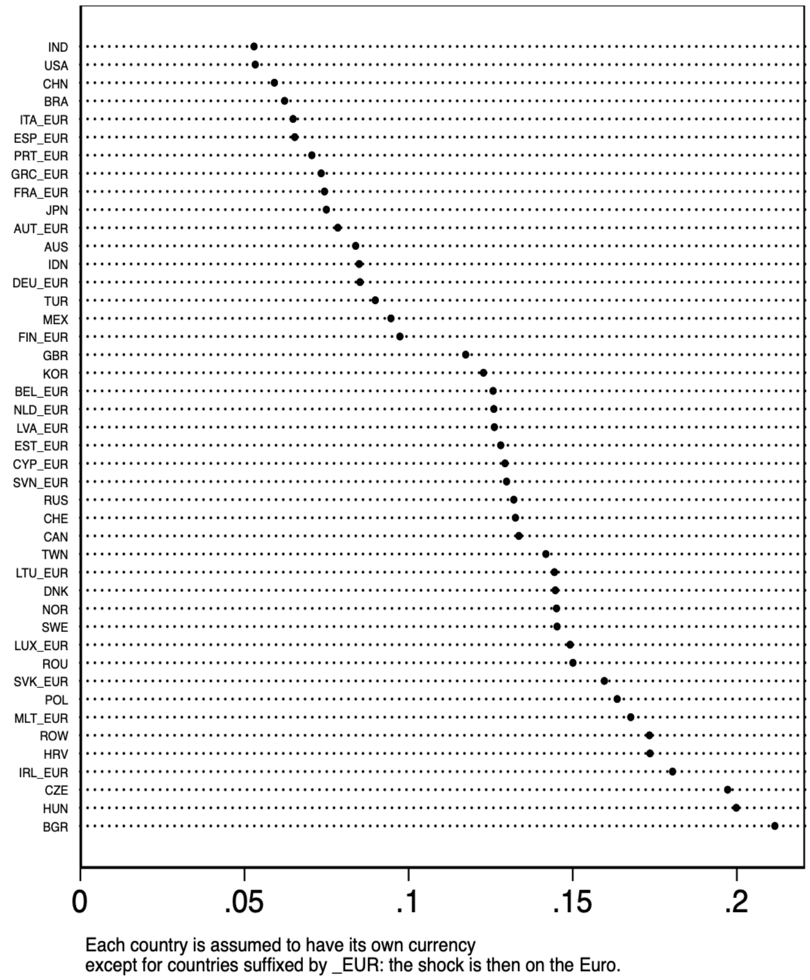

Fig. 1: **Elasticity of the HCE deflator to the domestic currency (WIOD), 2014.**

Sources: WIOD and authors' calculations.

Caveats and comparison with the literature Our computations rely on several simplifying assumptions that bias our estimates upwards.

First, we assume that exchange rate fluctuations completely pass-through to import prices. However, a large body of literature suggests that the pass-through is incomplete, even in the long run, as a result of slow nominal price adjustments or the pricing-to-market behavior of firms.[14] Hence, pricing-to-market strategies of exporters aiming to defend their market shares would imply a lower exchange rate pass-through. As a result, our estimates provide an upper bound of the HCE deflator elasticity compared to other results in the literature.

In addition, we work under the producer pricing assumption. However, in large and attractive markets, competitive pressures may push producers to adopt local currency pricing strategies, where exporting firms adapt their mark-ups depending on the destination market to offset exchange rate movements. Under the local currency pricing paradigm, prices are thus sticky in the currency of the destination market. Hence, using alternative pricing assumptions would entail lower estimates of the HCE deflator's elasticity. The magnitude of the upward bias stemming from our simplifying assumptions is unlikely to be constant in our sample given the cross-country heterogeneity. In particular, in large and attractive markets, competitive pressures may push producers to adopt local currency pricing strategies, where exporting firms adapt their mark-ups depending on the destination market to offset exchange rate movements. Hence, we would expect the upward bias in our estimated elasticities to be more pronounced for the largest and most attractive markets represented in our sample.

Despite these caveats, our results broadly concur with the literature. Aydoğuş et al. (2018) examine the pass-through to the domestic price level through an input–output model for 26 countries and 27 sectors, using I-O tables from the OECD Stan Database. Just like us, the authors provide an upper bound and conclude that results from the I-O model are not excessively high compared to the ERPT literature. Overall, the correlation coefficient between our respective estimates, computed on a sample of 26 countries, is 0.7. The estimated pass-through of an exchange rate shock to the CPI ranges from 0.07 for the US to 0.34 for Ireland, with a simple average of 0.18. Elasticities estimated by Aydoğuş et al. (2018) tend to be slightly higher than

[14] For example, the pass-through depends on the intensity of competition in domestic markets: while an appreciation of the exchange rate lowers the price of imported inputs, a firm with limited competitive pressure may avail itself of greater profit margins rather than reduce prices in an effort to maintain its market share. Based on Belgian firm-product-level data, Amiti et al. (2012) find that import intensity and market share are key determinants of the ERPT to export prices.

ours. For instance, our results concur for Australia, the US, Brazil, or Canada. However, the authors find an elasticity close to 0.16 for France, Germany, Italy and Spain, whereas our results are closer to 0.10. Elasticities estimated by Aydoğuş et al. (2018) are much higher for Estonia and Ireland (respectively, 0.31 and 0.33 vs. 0.15 and 0.18 according to our computations).
Colavecchio and Rubene (2020) compute the ERPT to consumer prices in the euro area from 1997 to 2019 using local projection techniques.[15] The authors find a statistically significant linear ERPT to domestic prices of 0.07 for Italy, 0.08 for Belgium and Portugal, 0.09 for Germany, 0.12 for Spain, 0.13 for Austria and Greece, 0.14 for the Netherlands and Finland, and 0.23 for Lithuania after two years.[16] These figures concur with our estimates, which range from 0.07 to 0.18 for euro area countries (see Figure 1).

Robustness We use several datasets for the sake of robustness. Overall, results obtained with different databases are consistent. For instance, Figure 2 compares the results obtained with WIOD and those obtained with two distinct releases of TiVA for 2011 and 2014.

[15] To the best of our knowledge, the literature using WIOTs mostly focuses on the transmission of production shocks through input-output linkages. By contrast, we use WIOTs to analyze cost-push inflation. As a result, and despite differences in methodologies, we compare our estimates of the HCE deflator elasticity with results from the ERPT literature.

[16] The linear ERPT to consumer prices estimated by Colavecchio and Rubene (2020) for the euro area as a whole is not statistically significant.

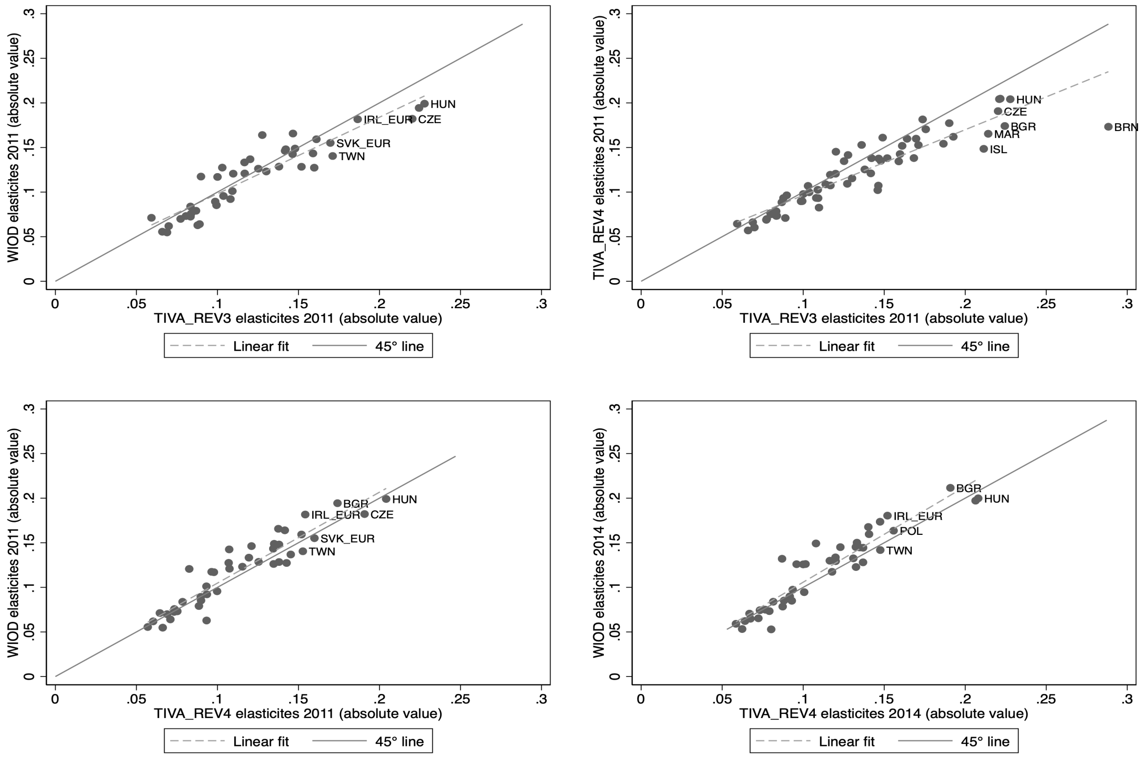

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Fig. 2: **Comparison of the HCE deflator elasticity to the exchange rate for WIOD, TIVA rev. 3 and TIVA rev. 4 (2011 and 2014)**

Sources: WIOD, TIVA rev. 3 and TIVA rev. 4, authors' calculations

Figure 3 shows that the value of the elasticity is closely, but not perfectly, related to the share of imported goods and services (from outside the euro area for euro area countries) in household consumption. The higher the country's import share in consumption, the higher the elasticity of the HCE deflator to the exchange rate.[17]

[17] See section 4 for more details on the relationships between the HCE deflator and various indicators of trade openness.

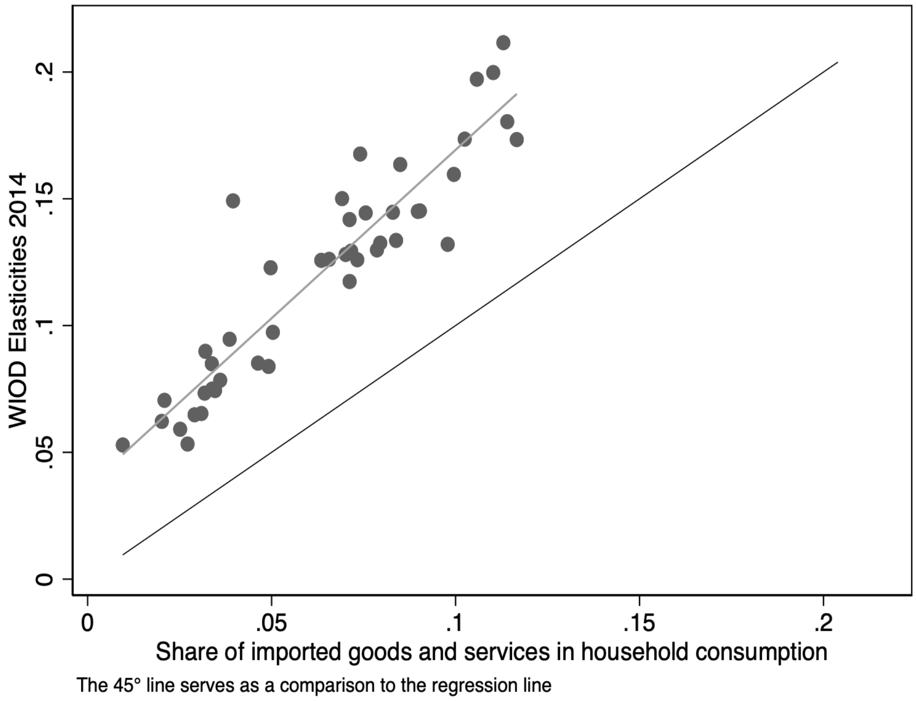

Fig. 3: **HCE deflator elasticity and share of imported consumption in total consumption (WIOD, 2014)**

Sources: WIOD and authors' calculations

3.2 Impact of an appreciation of the US dollar

Results We can use the model to track the effect on the domestic economy of variations in the currency of foreign countries. For the sake of illustration, we estimate the impact of an appreciation of the US dollar (USD) using WIOD. This exercise assumes that exports are always invoiced in the exporter's currency. Hence, we do not take into account the large role of the dollar in international trade invoicing. The US example illustrates that countries are affected in proportion to their trading links with the country whose currency appreciates. We obtain the highest elasticities for the major trading partners of the US. The elasticity of the HCE deflator to the USD amounts to 0.12 for Canada and 0.09 for Mexico (see Figure 4). The elasticity is below 0.06 for most euro area countries. Ireland stands out, with an elasticity of 0.09, i.e. close to that of Canada and Mexico.[18]

[18] The US. is Ireland's major trading partner outside of the EU, even if a large portion of Irish imports from the US (pharmaceuticals and aircraft) are later exported by Irish-based firms without being purchased by Irish consumers (Reddan and Rice, 2017), and therefore have a negligible contribution to domestic consumer goods inflation.

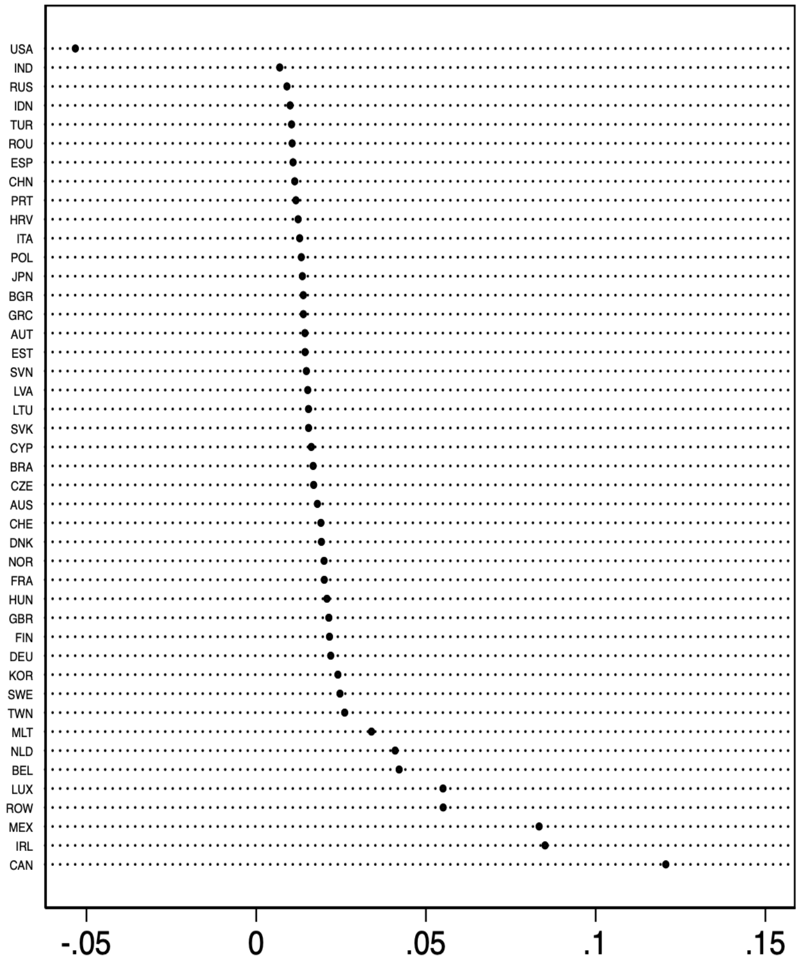

Fig. 4: **Elasticity of the HCE deflator to the US dollar (WIOD) - 2014.**

Sources: WIOD and authors' calculations.

Caveats As underlined above, our computations rely on several simplifying assumptions which bias our estimates upwards. Although we assume a full exchange rate pass-through, the theoretical framework underlying the "dominant currency paradigm" (DCP) predicts that pass-through from exchange rates to prices or quantities vary across countries, depending on the share of imports invoiced in dollars. For instance, Boz et al. (2019) find that the dollar pass-through is systematically related to the importing country's dollar invoicing share. According to the authors, importing country's share of imports invoiced in dollars explains 15% of the variance of dollar pass-through across country pairs. Country pairs with the largest-in-magnitude pass-through of the dollar into prices or quantities tend to be the dyads with the highest importer dollar invoicing share. These findings suggest that the upward bias in our estimates is unlikely to be constant across countries. Since the DCP literature suggests that countries invoicing more in US dollars tend to experience greater US dollar exchange rate pass-through to their import prices, we expect the upward bias in our estimates to be minor for those economies.

We assess cross-countries variations in the upward bias by building on Boz et al. (2020), which document the role of vehicle currency invoicing for exchange rate pass-through to import prices for around 100 countries since 1990.[19] According to Boz et al. (2020), in 2014 (the year for which we provide estimates of the HCE deflator elasticity in Figure 4), the following countries had the largest share of imports invoiced in US dollar: India (89% of imports), Brazil (81%[20]), Taiwan (80%[21]), Indonesia (76%), South Korea (84%), Japan (74%), Turkey (63%) and Australia (57%). Invoicing in US dollar was less prevalent in Europe (where invoicing in euro dominates), ranging from around 20% (Croatia, Estonia, France, Germany, Hungary, Malta, Norway and Slovenia) to 30% (Denmark, Finland, Ireland, Italy, Poland, Romania, Switzerland, Sweden, the Netherlands). Invoicing in US dollar was close to 40% in Spain, Lithuania, the UK, Russia and as high as 50% in Greece. By contrast, it was much lower for Latvia (7%[22]) and Luxembourg (11%[23]), suggesting that the upward bias in our estimates is particularly pronounced for these two economies.

3.3 Evolution over time of the HCE deflator elasticity

The output-weighted elasticity of the HCE deflator to the exchange rate has remained broadly stable over the past two decades. Output-weighted elasticities are lower than arithmetic means, reflecting the fact that large countries are relatively closed compared to small economies. Using WIOD, we find that the mean output-weighted elasticity of the HCE deflator increased from 0.06 in 2000 to 0.08 in 2008 (see Figure 5). After peaking in 2008, the elasticity sharply declined in 2009. It has hovered around 0.08 in subsequent years. Our results concur with the literature. Using comprehensive measures of global value chain integration, Timmer et al. (2016) find that the expansion of global value chain has slowed down since the Great Recession.

While the latest dataset available for WIOD dates back to 2014, MRIO covers the most recent

[19] Invoicing data are not available for several large countries, including China and Mexico.
[20] In 2017 (data unavailable for 2014).
[21] In 2016 (data unavailable for 2014).
[22] In 2015 (data unavailable for 2014).
[23] In 2016 (data unavailable for 2014).

years, up to 2019. Results from the MRIO database suggest that the elasticity has bounced back from 2016 onwards, reaching 0.09 in 2019. However, the version of MRIO we use (March 2021 release) suffers from data quality issues for 2018 and 2019.[24] Hence, we assume that the elasticity estimated using MRIO is not reliable for 2018 and 2019 (see Section 4.3 for further details).

Overall, our estimates are robust to using different databases. WIOD and MRIO provide similar elasticities. The main difference between the two databases relates to the broader geographic coverage of MRIO, which includes nineteen additional emerging Asian economies. Given the relative small size of these economies, using MRIO provides aggregate results similar to those of WIOD. By contrast, using data from TiVA rev.3, which covers a sample of 64 countries up to 2011, yields a higher elasticity. TiVA rev.3 suggests that the output-weighted elasticity has increased by 25% between 1995 and 2008, reaching 0.10 in 2008.[25]

The slight differences observed between WIOD and TiVA rev.4 likely reflect different ways of reconciling national accounts and international trade statistics.

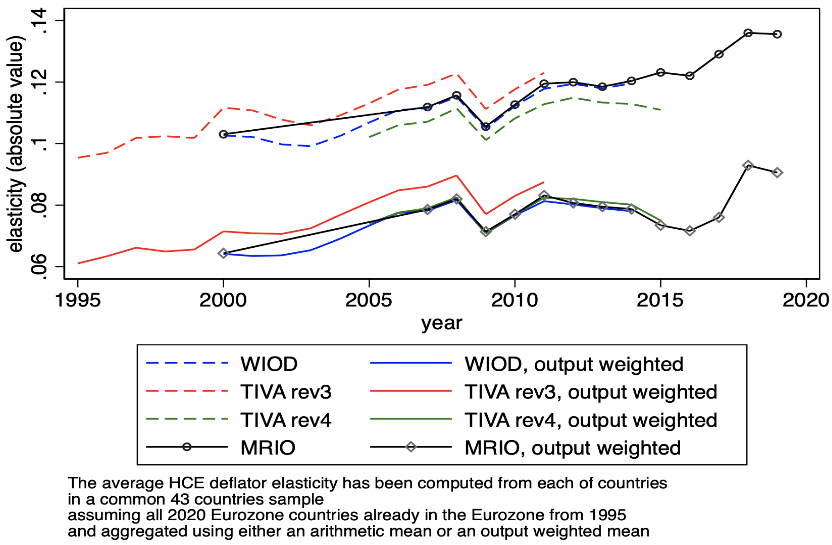

Fig. 5: **Evolution of the HCE deflator elasticity, 1995-2019**

Sources: WIOD, MRIO, TIVA rev.3, TIVA rev.4 and authors' calculations

[24] Between 2017 and 2018, according to the MRIO database, the HCE deflator elasticity sharply increased in a number of countries (e.g. China and India). See Online Appendix D for more details.

[25] The third revision of TiVA is based on the 1993 system of national accounts, whereas the fourth revision is based on the 2008 system of national accounts. The higher estimates obtained with TiVA rev.3 likely reflects the different treatment of contract manufacturing in the 2008 system of national accounts compared to the 1993 system, which reduces imported inputs.

3.4 Contributors to the HCE deflator elasticity

In this section, we analyze the contributions of each part of the consumption basket to the pass-through of exchange rate variations to consumer prices. We start with the contributions of domestic versus imported goods.

We define

$$\overline{s}_{i}^{i,HC} = \overline{s}_{i,imp}^{i,HC} + \overline{s}_{i,dom}^{i,HC} = S^{i}.HC^{i,dom} + S^{i}.HC^{i,imp} \tag{10}$$

Where:

$$\begin{aligned} HC^{i} &= HC^{i,dom} + HC^{i,imp} \\ &= \begin{pmatrix} 0 \\ ... \\ \frac{hc_{ij}^{i}}{hc^{i}} \\ ... \\ 0 \end{pmatrix} + \begin{pmatrix} \frac{hc_{11}^{i}}{hc^{i}} \\ ... \\ 0 \\ ... \\ \frac{hc_{IJ}^{i}}{hc^{i}} \end{pmatrix} \end{aligned} \tag{11}$$

For example,

$$\overline{s}_{i,imp}^{i,HC} = \sum_{\substack{j=1...J \\ k=1...I \\ k\neq i}} s_{kj}^{i}.\frac{hc_{kj}^{i}}{hc^{i}} \tag{12}$$

Figure 6 shows that changes in the prices of imported final consumer goods and services contribute more to the total effect than changes in the prices of domestic final goods and services. Furthermore, imported final consumer goods also explain the differences in price elasticities observed between open and relatively closed economies. Although imported final consumer goods account for a smaller share of total consumption than domestic goods, they are the most impacted by exchange rate fluctuations.

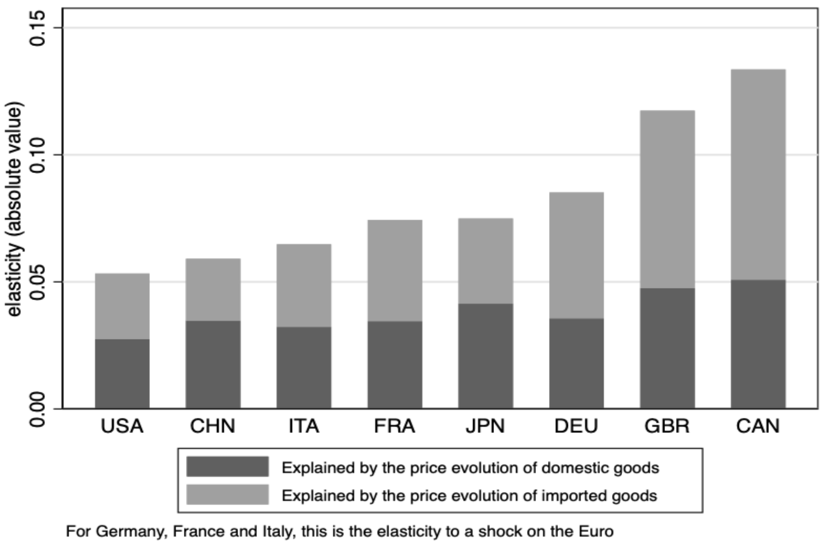

Fig. 6: **Contribution of imported and domestic final goods and services to the HCE deflator elasticity (WIOD, 2014)**

Sources: WIOD and authors' calculations

We also examine the contributions of each sectors to the HCE deflator elasticity. We regroup industries into four categories: *i)* manufacturing goods, *ii)* services, *iii)* food and *iv)* energy. Figure 7 shows the impact of a change in the exchange rate on the main components of the HCE deflator. Non-energy industrial goods explain the bulk of the total impact. However, services also play a significant role, especially in advanced economies. Although services are mainly produced domestically and do not require much imported inputs, they represent a substantial share of total consumption. Hence, even small price changes have large impacts on the HCE deflator. Finally, mixing both the industrial and origin analyses, we show that domestic core inflation (i.e. all domestic products except food and energy) accounts for a significant share of the total impact (Figure 8), reflecting the weight of domestic services and non-energy industrial goods in total consumption.

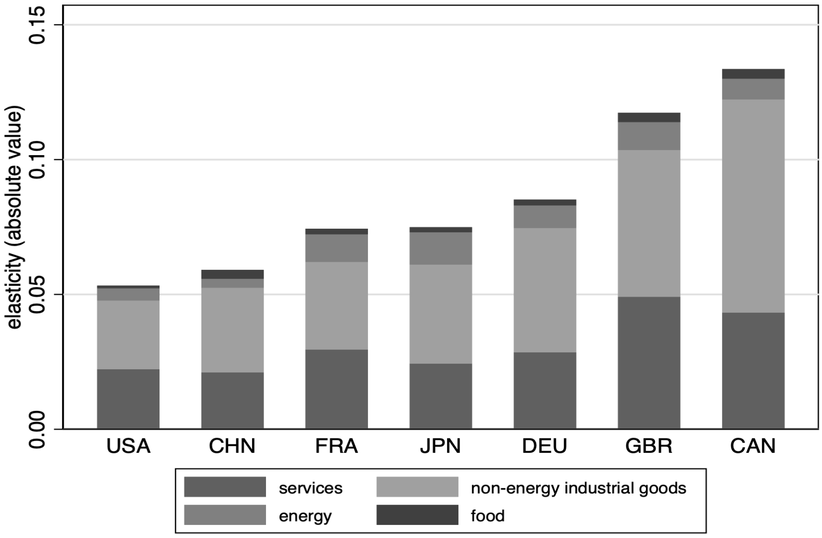

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Fig. 7: **Contribution of different products to the HCE deflator elasticity (WIOD, 2014)**

Sources: WIOD and authors' calculations

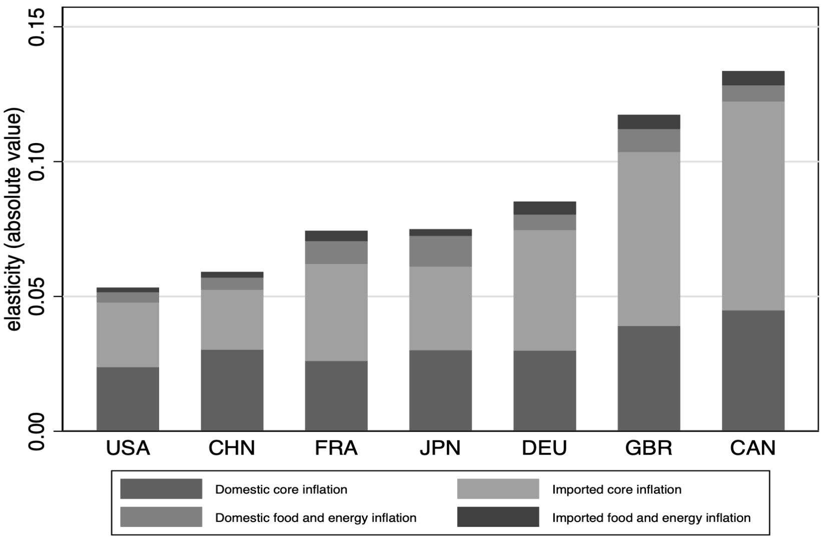

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Fig. 8: **Contribution of domestic and imported components to the HCE deflator elasticity (WIOD, 2014)**

Sources: WIOD and authors's calculations

4 Filling the data gap: estimating the HCE deflator elasticity without resorting to WIOTs

4.1 Assessing the role of global value chains in the transmission of exchange rate variations to domestic prices

In this section, we analyze the determinants of the HCE deflator elasticity. In particular, we assess the role of global value chains in the transmission of an exchange rate appreciation to the HCE deflator.

We identify four channels through which an exchange rate appreciation impacts the HCE deflator when production processes are global: *i)* the prices of imported final goods sold directly to domestic consumers; *ii)* the prices of imported inputs entering domestic production; *iii)* the price of exported inputs feeding through imported foreign production; *iv)* changes in domestic and foreign production costs in turn passing through to the price of inputs for domestic and foreign goods and causing further changes in production costs through input-output linkages. These two latter channels reflect the impact of global value chains.

Mathematically, we break down $\overline{s_i}^{i,HC}$ into these four elements. Starting from equation 8, we have:

$$\begin{aligned} S^i &= C^i + \left(\hat{C}^i_{\$}.\mathcal{B}^i + C^i\tilde{\mathcal{B}^i}\right) * (I-\mathcal{A})^{-1} \\ S^i &= \underbrace{C^i}_{\substack{\text{(E1) direct effect through} \\ \text{imported consumption goods}}} + \underbrace{C^i\tilde{\mathcal{B}^i}}_{\substack{\text{(E2) effect on} \\ \textit{domestic}\text{ consumption goods} \\ \text{through }\textit{imported}\text{ inputs}}} + \underbrace{\hat{C}^i_{\$}.\mathcal{B}^i}_{\substack{\text{(E3) effect on} \\ \textit{imported}\text{ consumption goods} \\ \text{through }\textit{domestic}\text{ inputs}}} \\ &+ \underbrace{\left(\hat{C}^i_{\$}.\mathcal{B}^i + C^i\tilde{\mathcal{B}^i}\right) * (I-\mathcal{A})^{-1} * \mathcal{A}}_{\text{(E4) residual}} \end{aligned} \tag{13}$$

Defining $HC^{i,dom}$ and $HC^{i,imp}$ as the domestic and imported shares of HC^i and adjusting the dimension of $E1$, $E2$ and $E3$, we have:

$$\begin{aligned} \overline{s}_i^{i,HC} &= S^i.HC^i = E1.HC^i + E2.HC^i + E3.HC^i + E4.HC^i \\ &= E1.HC^{i,imp} + E2.HC^{i,dom} + E3.HC^{i,imp} + E4.HC^i \end{aligned} \tag{14}$$

When the domestic currency appreciates, $E1.HC^{i,imp}$ ($E1.HC$ hereafter) and $E2.HC^{i,dom}$ ($E2.HC$ hereafter) reduce consumer prices in country i, whereas $E3.HC^{i,imp}$ ($E3.HC$) increases them.[26] Figure 9 plots the shares of $E1.HC$, $E2.HC$, $E3.HC$ and $E4.HC^{i}$ ($E4.HC$) in $\bar{s}_i^{i,HC}$. Direct effects through imported consumer goods ($E1.HC$) dominate. The effect on domestic consumer goods through imported inputs ($E2.HC$) is also important. By contrast, other channels reflecting the impact of global value chains ($E3.HC$ and $E4.HC$) play a more limited role, with marked cross-countries heterogeneity. The effect on imported consumer goods through domestic inputs ($E3.HC$) is negligible, except for Germany and the Netherlands. The residual $E4.HC$ accounts for 10% to 30% of $\bar{s}_i^{i,HC}$ for most countries (and close to 50% for India, Brazil, Portugal and Luxembourg). With the exception of Luxembourg, the less open to trade is a country, the larger the share of $E4.HC$.

Figure 10 shows that input-output mechanisms (i.e. all channels except $E1.HC$) explain a large share of the HCE deflator elasticity, especially for large countries or euro area countries. Figure 11 shows that input-output mechanisms have explained an ever increasing share of the HCE deflator elasticity since the early 2000s, implying a greater need of data from WIOTs to perform our computations.

[26] Note that this decomposition differs from equation 10. Equation 10 focuses on the contribution of domestic versus imported goods to the HCE deflator elasticity to the exchange rate. By contrast, Equation 14 highlights the transmission channels of the exchange rate fluctuation.

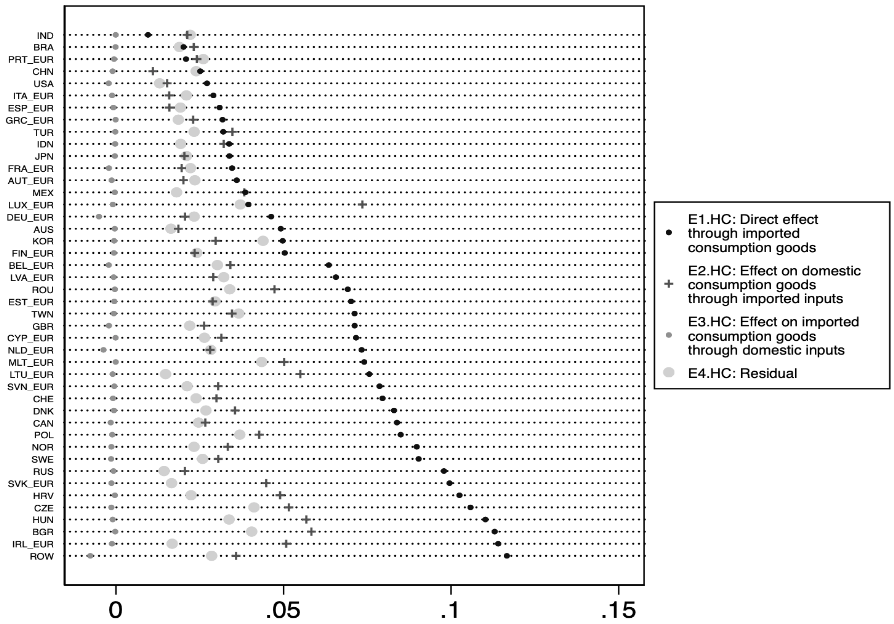

Fig. 9: **Decomposition of the HCE deflator elasticity into $E1.HC$, $E2.HC$, $E3.HC$ and $E4.HC$ (WIOD, 2014)**

Sources: WIOD and authors' calculations

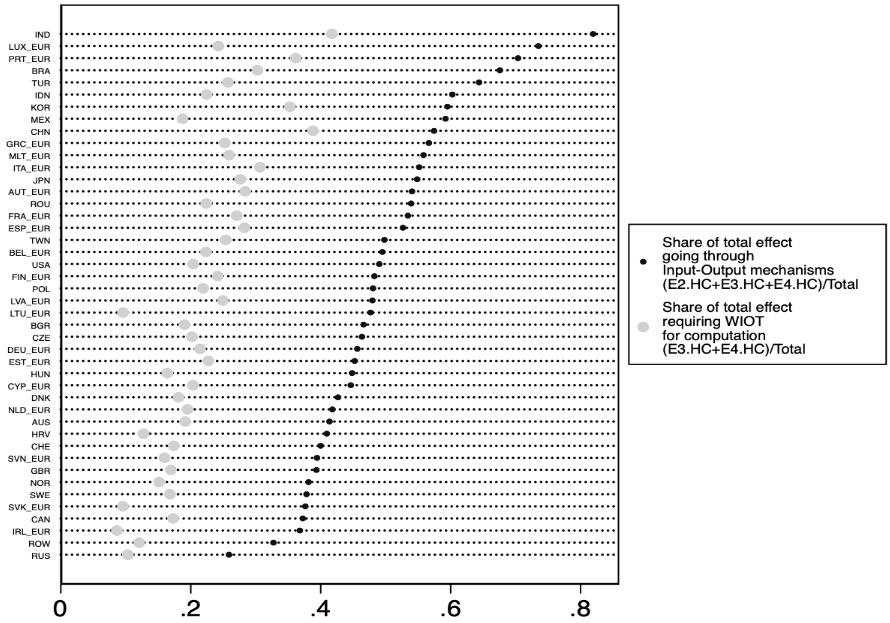

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Fig. 10: **The role of input-output mechanisms in explaining the HCE deflator elasticity (WIOD, 2014)**

Sources: WIOD and authors' calculations

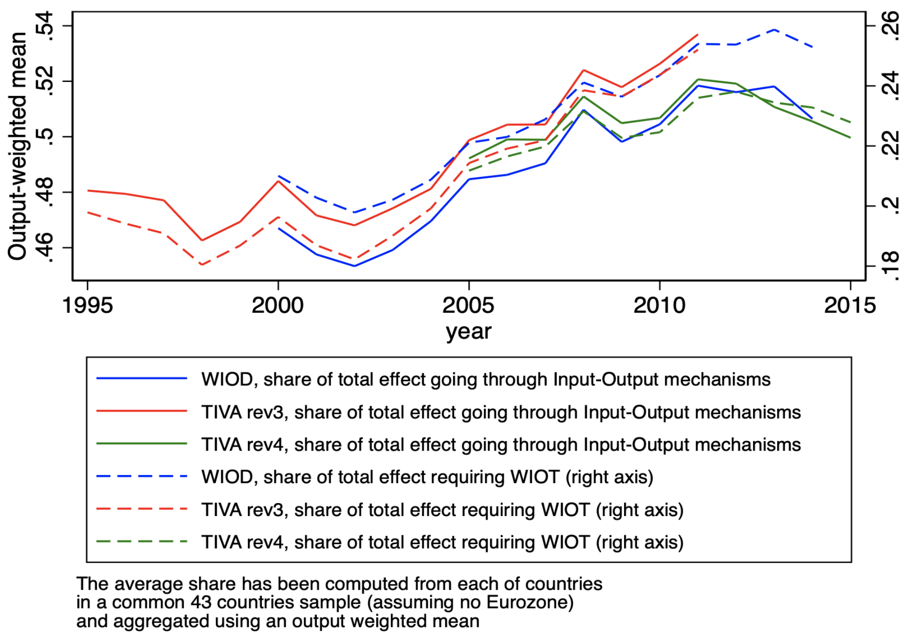

Fig. 11: **The increasing role of input-output mechanisms in explaining the HCE deflator elasticity over time**

Sources: WIOD, TIVA rev.3, TIVA rev.4 and authors' calculations

Overall, the main transmission channels are: i) the prices of imported final goods sold directly to domestic consumers and ii) the prices of imported inputs entering domestic production. These channels explain three-quarters of the transmission of an exchange rate appreciation to domestic prices and are particularly important for small economies. By contrast, the channels reflecting the impact of global value chains play a more limited role.[27]

4.2 Estimating the HCE deflator elasticity using the shares of imported goods and imported inputs in household consumption

In the section above, we have shown the decisive role of $E1.HC$ (the prices of imported final goods sold directly to domestic consumers) and $E2.HC$ (the prices of imported inputs entering domestic production) in explaining the HCE deflator elasticity to the exchange rate. The impor-

[27] Although the model as it stands cannot easily accommodate simultaneous exchange rate changes in different currencies (which would require increasing the number of $\mathcal{B}$ matrices and C vectors), we expect the effect of simultaneous variations of different currencies to be correctly approximated by an own-currency exchange rate change of the trade-weighted average of the country-specific exchange rate changes.

tance of these two channels suggests that the HCE deflator elasticity could be estimated using national accounts data and input-output matrices. National accounts data provide $E1.HC$ and $E2.HC$, whereas world input-output matrices are needed for computing $E3.HC$ (the effect on imported consumer goods through domestic inputs) and $E4.HC$ (the residual). We investigate whether $E3.HC$ and $E4.HC$ can be inferred from easier-to-compute elements of the HCE deflator elasticity ($\bar{s}_i^{i,HC}$). We infer $\bar{s}_i^{i,HC}$ from $E1.HC$ and $E2.HC$ using Equation 15.
Figure 12 depicts the relationship between $\bar{s}_i^{i,HC}$ and $E1.HC + E2.HC$. The high R^2 (0.98) suggests that $E1.HC + E2.HC$ is a good predictor of the HCE deflator elasticity ($\bar{s}_i^{i,HC}$).

$$\bar{s}_i^{i,HC} = \alpha + \beta \left(E1.HC^{i,imp} + E2.HC^{i,dom} \right) + \varepsilon_i \tag{15}$$

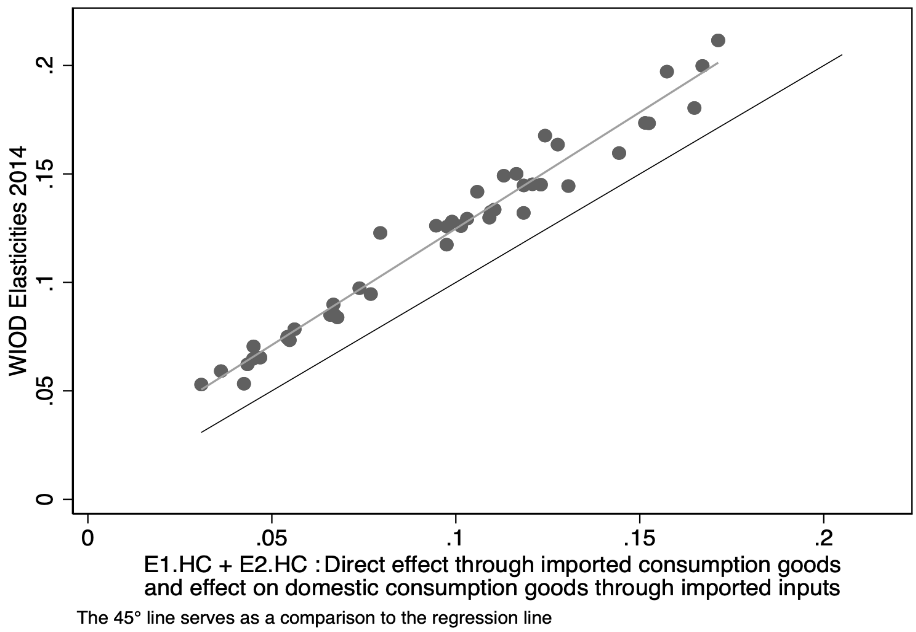

Fig. 12: **Estimating the HCE deflator elasticity using the shares of imported goods and imported inputs in household consumption (WIOD, 2014)**

Sources: WIOD and authors' calculations

We check whether the relationship is constant over time by estimating yearly cross-sections of Equation 15. With the exception of 2009, the relationship is broadly stable (see Figures 13).

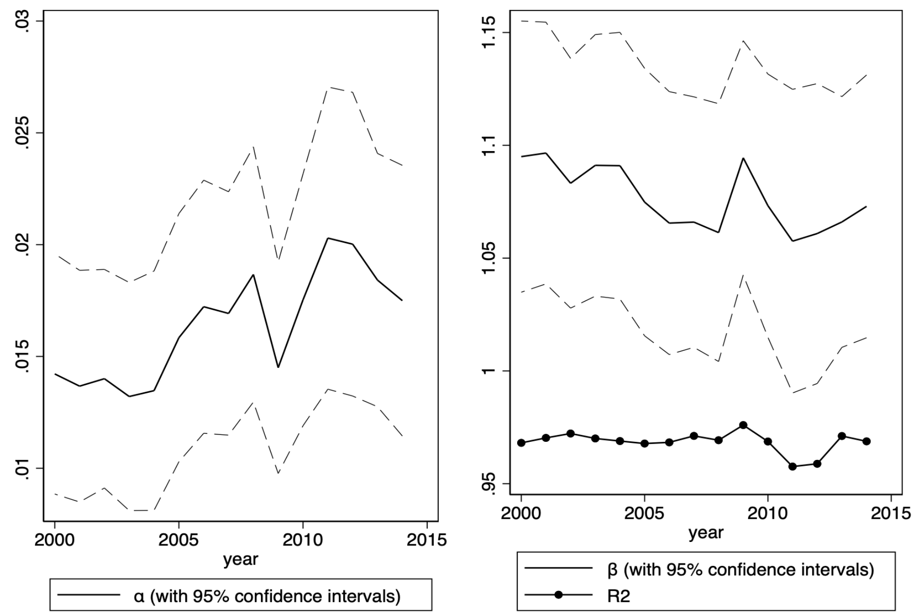

Fig. 13: **Estimating the HCE deflator elasticity using the shares of imported goods and imported inputs in household consumption: evolution of the constant (α), the coefficent of E1.HC+E2.HC (β) and R^2 over time**

Sources: WIOD and authors' calculations

We obtain similar results with TiVA (see Online Appendix E). Our results suggest that we can approximate the HCE deflator elasticity using the share of imported goods in household consumption and the share of imported inputs in household consumption of domestic goods. Indeed, $E1.HC + E2.HC$ is a good predictor of the total effects.[28]

4.3 Extrapolating the HCE deflator elasticity using GDP and trade statistics

In this section, we show that a precise assessment of the HCE deflator elasticity to the exchange rate can be estimated without resorting to WIOTs. The construction of World Input-Output tables is data-demanding and WIOTs are typically released with a lag of several years. As a result, world input-output matrices are not available for the most recent years. The latest years covered by WIOD and TiVA rev.4 are, respectively, 2014 and 2015. While the MRIO database

[28] Interestingly, the total effects cannot be extrapolated in a multiplicative way, as the other effects ($E3.HC + E4.HC$) add to $E1.HC + E2.HC$ rather than amplifying them. They are of similar size for small open economies and large closed ones. This likely reflects the fact that a small economy compensates for its small size (and small influence on global value chains) by being more open (and hence more sensitive to changes in global value chains). Although this functional form might seem counterintuitive (we expected the elasticity to be an affine function of openness as summarized by $E1.HC$), the analytical examination of the two-country, one-sector case shows that it is plausible (see Online Appendix F).

covers more recent years, it is fraught with data quality issues for 2018 (see Section 3.3 and Online Appendix D). Using WIOTs also involves cumbersome computations. Given these difficulties, we look for a simpler way to compute the elasticity of the HCE deflator to the exchange rate. We estimate the HCE deflator elasticity from 2015 onwards using GDP statistics and trade data on consumption and intermediates.

As discussed above (see section 4.2), the sum of the share of imported goods in household consumption and the share of imported inputs in household consumption of domestic goods ($E1.HC + E2.HC$) is a good predictor of the impact of exchange rate fluctuations on household consumption prices. However, these data ($E1.HC$ and $E2.HC$) are not up-to-date for a large number of countries, as they are not routinely computed by national statistical institutes. Hence, we cannot use them to extrapolate the HCE deflator elasticity.

Consumption and intermediate goods imports are available from the CEPII BACI database and the BEC classification (Gaulier and Zignago, 2010).[29] Still, household consumption and intermediate products are more difficult to collect systematically for most countries and years.[30]

Here, we use a simple proxy for $E1.HC$ and $E2.HC$, using trade data from BACI and GDP data from the World Bank for a panel of 42 countries. These data are available until 2019. Since we aim to perform an out-of-sample prediction, we do not use time fixed-effects. We assume instead that each year is characterised by the importance of imported consumption and intermediate goods over the whole sample (see equation 16). We use country fixed-effects (fe_i).

$$
\begin{aligned}
\overline{s}_{i,t}^{i,t,HC} = \; & \beta_1 \frac{\text{imported consumption goods}_{i,t}}{\text{GDP}_{i,t}} \\
& + \beta_2 \frac{\text{imported intermediate goods}_{i,t}}{\text{GDP}_{i,t}} \\
& + \beta_3 \frac{\text{Total sample imported consumption goods}_t}{\text{Total sample GDP}_t} \\
& + \beta_4 \frac{\text{Total sample imported intermediate goods}_t}{\text{Total sample GDP}_t} \\
& + fe_i + \varepsilon_{i,t}
\end{aligned} \tag{16}
$$

We start by estimating Equation 16 on all three databases (WIOD, TiVA rev. 3 and rev.4) for all available years. Table 3 provides the estimation results. Individual coefficents and their statistical significance are difficult to interpret because of multicollinearities among the explanatory variables. We rather focus on the quality of the model fit, since we aim to perform predictions.

[29] BACI provides disaggregated data on bilateral trade flows for more than 5000 products and 200 countries. The database is built from data directly reported by each country to the United Nations Statistical Division (Comtrade). Products are defined as items from the Harmonized System nomenclature, at the 6-digit level.

[30] To illustrate this point, in Online Appendix G we use data from the World Bank and Eurostat, which are available for only 29 countries in our sample.

	(1) WIOD	(2) TIVA	(3) TIVA REV4
β_1	0.49***	0.19	0.09
	(0.17)	(0.17)	(0.16)
β_2	0.10***	0.09**	0.11***
	(0.03)	(0.04)	(0.04)
β_3	0.25	-0.23	1.25**
	(0.43)	(0.59)	(0.60)
β_4	0.27***	0.35***	0.20***
	(0.05)	(0.10)	(0.04)
Observations	630	629	506
Country fixed effects	Yes	Yes	Yes
Number of countries	42	45	46
Number of years	15	14	11
Adj. R-square	0.98	0.96	0.97
p-value joint significance test (excluding fixed effects)	0	0	0

Note: Country-clustered standard errors in parentheses, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Tab. 3: Regression results for Equation 16 for WIOD, TiVA rev.3 and TiVA rev.4, using all available years

To confirm the quality of fit, we perform an out-of-sample prediction for the year 2014 using WIOD, running the regression on the years 2000 to 2008.[31] The results of the out-of-sample prediction are close to the WIOT-computed elasticities for 2014 (see Figure 14). Our findings are robust to using other databases.[32]

Overall, the quality of fit of Equation 16 shown in Table 3 is high and the out-of-sample prediction for 2014 is very similar to the elasticities computed using WIOTs (figure 14). Figure 15 shows that our in-sample forecasts (in dotted lines) are very close to elasticities computed using WIOTs (plain lines). We also compare our predictions with the elaticity estimated using MRIO, which provides WIOTs up to 2019. Our predictions are in line with results from MRIO up to 2017.[33] Overall, our out-of-sample forecasts using up-to-date trade and GDP statistics are good proxies for the elasticities computed using WIOTs. Hence, we can use the regression results presented in table 3 to predict the HCE deflator elasticity for the years for which WIOTs are not available, especially from 2015 onwards. We thus provide a tool to estimate the elasticity of

[31] Regression results are similar to those presented in Table 3 and are available upon request.
[32] Results obtained with TiVA revisions 3 and 4 are available upon request.
[33] For the most recent years, there are data quality issues in MRIO (see Online Appendix D), which the comparison between our prediction and the elasticity computed using MRIO further underlines.

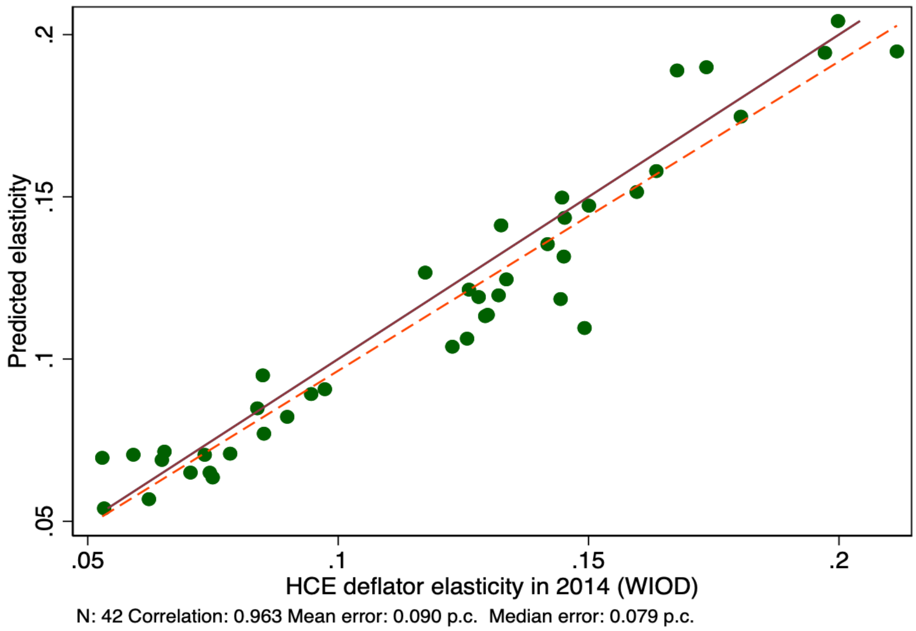

Fig. 14: **Comparing the HCE deflator elasticity in 2014 (WIOD) and the prediction from a panel regression on the 2000-2008 period with fixed-effects**

Sources: WIOD, World Bank, BACI and authors' calculations

domestic prices to the exchange rate for the most recent years. Most of the existing literature focuses on average elasticities, computed over a period covering several years. By contrast, our proxies make it possible to highlight how elasticities evolve from one year to the next in an up-to-date way.

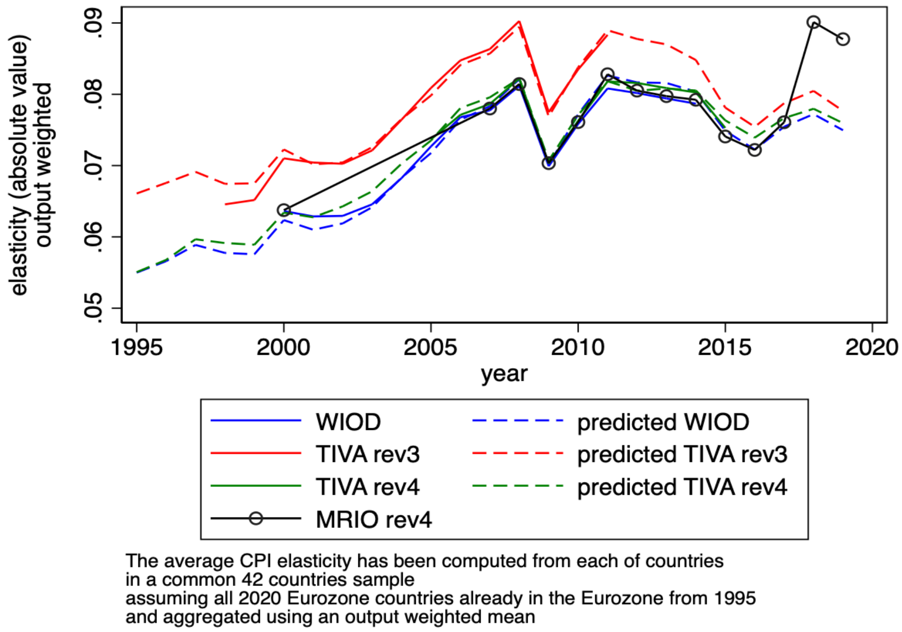

Fig. 15: **Comparing the output-weighted HCE deflator elasticity computed using WIOTs to proxies based on up-to-date trade and GDP statistics.**

Sources: WIOD, TIVA, MRIO, World Bank, BACI and authors' calculations

5 Conclusion

This paper studies the elasticity of the household consumption expenditure (HCE) deflator to the exchange rate for a sample covering most advanced and emerging economies. We perform an accounting exercise based on information contained in world input-output tables. Our accounting approach helps identify which countries and sectors are under pressure to adjust their prices when subject to an exchange rate variation. We make several assumptions to simplify our computations. As a result, our estimates provide an upper bound of the HCE deflator elasticity. We make several contributions to the literature.

First, we analyse the composition and determinants of the HCE deflator elasticity using world input-output tables covering twenty-four years of data, from 1995 to 2019. We use several datasets to ensure the robustness of our results. In line with the existing literature, we find a rather modest output-weighted elasticity of the HCE deflator to the exchange rate of around 0.1 at the world level. The output-weighted elasticity has remained broadly stable over the past two decades. Aggregate figures mask substantial cross-country heterogeneity, reflecting different degrees of openness to trade and differences in foreign product content in domestic consumption. The impact of a 1% exchange rate fluctuation on domestic prices ranges from 0.05% to 0.22%. The elasticity is larger for small open economies with higher import content of consumption. In the euro area, the elasticity is close to 0.10 in Italy, France, Germany, Spain, Portugal and Greece, whereas it is twice higher for small open economies like Luxembourg, Malta, Slovakia and Ireland.

Second, we estimate the impact of an appreciation of the US dollar on its trading partners. The highest impacts are observed for the US's major trading partners (Canada, Mexico and Ireland).

Third, we examine which parts of the consumption basket contribute most to the elasticity of the HCE deflator to the exchange rate. Non-energy industrial goods explain the bulk of the total HCE deflator elasticity. Services also play a significant role, especially in advanced economies such as the US, Japan, Germany and France. Although services are mainly produced domestically and do not require much imported inputs, they account for a substantial share of total consumption. Thus, even small price changes have a large effect on the HCE deflator.

Fourth, we analyse the determinants of the HCE deflator elasticity and the role of global value chains in the transmission of an exchange rate appreciation to domestic prices. On the whole, direct effects through imported consumption and intermediates entering domestic production explain three-quarters of the transmission of an exchange rate appreciation to domestic prices. By contrast, global value chains participation plays a limited role.

Fifth, we show that a precise assessment of the HCE deflator elasticity to the exchange rate can be extrapolated for recent years, for which good-quality WIOTs are missing. We estimate the HCE deflator elasticity using GDP statistics and trade data on consumption and intermediates and obtain reliable out-of-sample predictions. While most of the existing literature focuses on average elasticities, computed over a period covering several years, this approach allows us to analyse how elasticities change in a more up-to-date way, from one year to another.

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