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The Inflexible Structure of Global Supply Chains

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Abstract

The rise of global supply chains has had profound effects on individual economies and the global trading system, thereby complicating standard macroeconomic analyses. For many of the new and challenging questions brought about by this phenomenon, such as its impact on the global business cycle and measurements of competitiveness, the answer largely depends on one specific aspect of global value chains: how easily they can re-configure in response to changes in prices. We propose a parsimonious, generalized specification to test the degree of global-supply-chain flexibility. Our estimates show that, in the short run, the production structure is highly inflexible, and that this rigidity has, if anything, risen over time as supply chains have deepened over time. This finding is robust to alternative price measures, including those that account for the U.S. dollar's outsized role in trade through invoicing. While in the long run all estimated elasticities rise, supply chains remain somewhat inflexible. Our results have implications for analyses of cross-country business-cycle dynamics, the propagation of sectoral shocks, and the measurement of international competitiveness.

JEL Classification Numbers: F15, F17, F62.

Keywords: Global supply chains, value-added trade, production and final-demand elasticities.

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I. INTRODUCTION

The rise of global value chains has been one of the most notable changes in the world economy of the last few decades (Baldwin, 2016). The breakup of large, relatively self-sufficient factories into smaller steps placed around the world has increased productivity, supported prosperity in many developing countries, relocated labor internationally, and changed the relationship between labor and capital. It has also had deep effects on the global trading system, with rapid increases in trade in intermediate goods.¹ However, it has also complicated macroeconomic analysis. It has changed cross-country business-cycle dynamics, made the analysis of propagation of shocks more difficult, and challenged our understanding of notions of competitiveness and trade openness. For many of these new and challenging questions, the answer largely depends on one specific aspect of global value chains: how easily they can re-configure in response to changes in prices. In this paper, we estimate the degree of flexibility of global supply chains using data for 59 advanced, emerging and developing economies over a period of 21 years.

If the production process is relatively flexible, with producers mixing inputs based on price signals, then the global trading system can be thought of as involving trade in “tasks”, with each little bit of the global value chain being semi-autonomous. If, on the other hand, such value chains are relatively inflexible, so that goods are combined in relatively fixed proportions with limited account of prices, then trade is better thought of as involving “goods”, with the various parts of the global value chain being combined to create a single product, implying much greater interdependencies across the chain.

The evidence presented in this paper clearly rejects the hypothesis that global supply chains are flexible. We first show how a reduced-form regression that relates relative price changes to the demand for value added should help elucidate the flexible or inflexible nature of global supply chains. We propose a parsimonious specification that nests both possibilities and

¹ See, for example, Dollar (2019) and annual Global Value Chain Development Report published by the World Trade Organization (World Trade Organization, various years).

allows the data to speak for themselves. Our estimates show that, in the short run, the production structure is in fact not too far from being completely inflexible, and that this rigidity seems to have increased over time as supply chains have become deeper. This finding is robust to alternative price measures, including those that account for the U.S. dollar's outsized role in trade due to invoicing (Boz, Gopinath, and Plagborg-Møller, 2018). Strikingly, supply chains remain somewhat inflexible even in the long run. In particular, while the longer horizon leads to larger elasticities in both production and final demand, complementarities in production persist. In other words, expenditure decisions at the production stage remain less flexible to price changes than final-demand expenditure decisions even in the long-run.

The paper contributes to three strands of macroeconomics literature. First, our findings lend empirical support to theoretical explanations of business cycle co-movements between countries. As established by the seminal paper by Frankel and Rose (1998), country pairs exhibit a positive relation between business cycle correlations and trade. Subsequent work showed that trade *in intermediates* in fact explains a large fraction of this effect of trade on output co-movements (di Giovanni and Levchenko, 2010). Burstein et al. (2008) explain the association between output correlations and production fragmentation with a model of business cycles the key assumption is that the elasticity of substitution in production is extremely low. More recent work by de Soyres (2017) shows that trade in intermediates is an essential ingredient to quantitatively explain the relationship between trade and GDP co-movements. In particular, his simulation results rely on a calibration where the elasticity of substitution between intermediates of different countries is one-fifth of the elasticity of substitution in final demand. To the best of our knowledge, this paper is the first to provide systematic cross-country evidence in support of these theoretical advances in international macroeconomics.

A somewhat related but distinct set of papers emphasizes that low production elasticities may not only explain output co-movements between countries, but also the importance of industry-specific shocks in explaining aggregate output fluctuations. Work by Acemoglu et al. (2012) has recently revived the interest in understanding the role of input-output linkages

in transmitting, and possibly amplifying, sectoral shocks, an idea with underpinnings going back to at least Long and Plosser (1983). A series of recent empirical contributions have drawn attention to the role of production complementarities as a key amplification mechanism that may lead sectoral shocks to have macroeconomic consequences; see e.g. Atalay (2017), Boehm, Flaaen and Pandalai-Nayar (2019), Barrot and Sauvagnat (2016) and Demir et al. (2017). This paper complements this literature by providing cross-country evidence on the flexibility of production networks over different time horizons. In particular, our results show that the findings for specific countries (notably, the U.S. and Japan) using specific events (such as natural disasters) appear to be a reflection of a widespread phenomenon of global production chains that, relative to final demand, are remarkably unresponsive to prices over periods of over 5 years, and that supply chains retain some degree of inflexibility even in the long run. Importantly, since these findings are not derived from *bilateral* trade data, they are not subject to the pervasive measurement inaccuracy that arises from the proportionality assumption in world input-output data (de Gortari, 2019).

Finally, the paper contributes to the literature on measuring international competitiveness in a world of global value chains. In an elegant paper, Bems and Johnson (2017) show how the standard real effective exchange rate formula first developed by Armington (1969a, 1969b) can be extended to account for trade in intermediate inputs. Bems and Johnson (2017) offer various possible calibrations of their demand system, each yielding conceptually and empirically different competitiveness weights depending on the relative price elasticity of production and final demand. Crucially, the question of which of these calibrations is more appropriate remains open. Building on the work by Bems and Johnson (2017), we are the first to answer the question. Our results show that over shorter horizons of about 5 years, global supply chains are remarkably inflexible.² In other words, to the question of whether

² In a somewhat related paper, Cheng et al. (2016) focus on estimating trade elasticities in the presence of global supply chains. Their approach, however, is different from the one presented here in crucial ways. All the analysis in Cheng et al. (2016) is based the exchange-rate elasticities of the foreign value added in exports of intermediates, which is what they denote as “GVC trade”. There are inherent limitations associated with this focus. Most importantly for our purposes, our specification, which focuses on exports to final demand and is carefully tailored to nest the possibility of very different global production structures, allows for a model-free test of which type of global-value-chain model is a better approximation of reality. Another limitation stems from the fact that, by focusing on exports of intermediates, their analysis ignores processed goods that are exported to final demand (see discussion in footnote 6 of Cheng et al., 2016). These intermediate goods close to

one should think of global-value-chain as trade in tasks (that are directly exported from the source to the final-demand country) or trade in goods (with goods prices reflecting the cost of tasks embedded in those goods; see Bayoumi et al., 2013), our answer is that over these horizons the latter is a more accurate characterization of the evidence.

The rest of the paper is organized as follows. Section II provides an illustration of the basic mechanisms at work that can help elicit from the data the degree of global-supply-chain flexibility. Section III operationalizes this illustration by providing a parsimonious reduced-form specification that can be used to test specific hypotheses about supply-chain flexibility. After presenting the data in Section IV, the results are discussed in Section V. In Section VI we show the implications of our estimates for trade and economic activity. Section VII concludes.

II. AN ILLUSTRATION

Central to our approach to testing the degree of flexibility of global supply chains is the observation that the demand effects of relative price changes are a function of the economy's production structure. More precisely, and as elegantly shown by Bems and Johnson (2017), how changes in relative prices translate into changes in the demand for value added (and thus into real GDP effects) depends on the relative elasticities in production and consumption.³ To fix ideas, consider the case of a 787 Dreamliner sold by Boeing (U.S.) to Qantas (Australia). Suppliers from all over the world contribute to the final product. To simplify things, assume the main fuselage is entirely made in the U.S., the wings are made in Japan, the engines in the UK, and the tail stabilizer in Italy.⁴ How should one think about the demand for the airplane and its components?

the final stages of production are arguably more differentiated, and thus more GVC-like, than the commoditized intermediates (crude oil, grains, etc.) that – in their data – therefore end up being overrepresented.

³ For a similar approach, see also Patel, Wang, and Wei (2017).

⁴ See “Boeing’s 787 Dreamliner Is Made of Parts from All Over the World,” *Business Insider*, October 10, 2013.

Consider first the possibility that the supply chain is *inflexible*. This means that Boeing will use the same inputs from the U.S., Japan, the UK and Italy no matter the inputs' prices – i.e. no matter how bilateral real exchange rates faced by Boeing evolve. Since only the behavior of final demand (i.e. the elasticity of Qantas' demand) matters, the price of each component of the plane will affect demand only and exactly to the extent that it contributes to the finished airplane. For instance, if the British component amounts to 10 percent of the value of the plane, then fluctuations between the Sterling and the Australian dollar will matter only in proportion to that 10-percent share. Because the entire finished good must be considered when gauging the demand effects of changes in the price of a single component, it is natural to think of this case as *trade in goods*. This is illustrated in panel (a) of Figure 1.

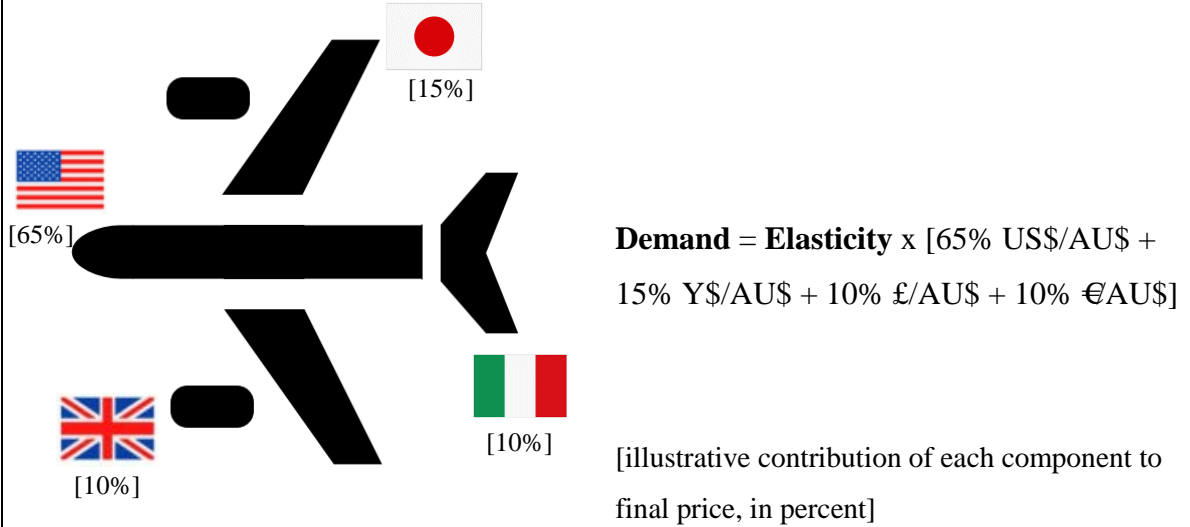
Alternatively, supply chains might be *flexible*, in that Boeing is in fact as likely to change supplier of components as the final consumer (Qantas) is likely to switch to a different product (say, an Airbus) in response to changes in prices. As it turns out, in this case the intermediate production process is simply a chimera. As shown more generally in Bems and Johnson (2017), each component of the airplane can be thought about as being directly exported from the country of the supplier to Australia. The fact that each component is incorporated into a single airplane along the way makes no difference. This is often termed *trade in tasks*, on the logic that a good is an amalgam of components (“tasks”) and that in this version of the model all that matters is the initial origin of the components which are incorporated in the final goods. Instead of the complementarity that arises under inflexible supply chains, under flexible supply chains it is effectively as if we had one different demand equation for each country. This is illustrated in panel (b) of Figure 1.

To sum up, the degree of flexibility of global supply chains manifests itself in which and how different relative prices matter for the final demand for value added. Under inflexible global supply chains, it is the price of the final good taken together that matters, so that any change in the relative price of a given fraction of value added will reverberate only to the extent to which it affects the price of this final composite good. Under flexible global supply chains, the relative price of this fraction of value added is the only relevant relative price.

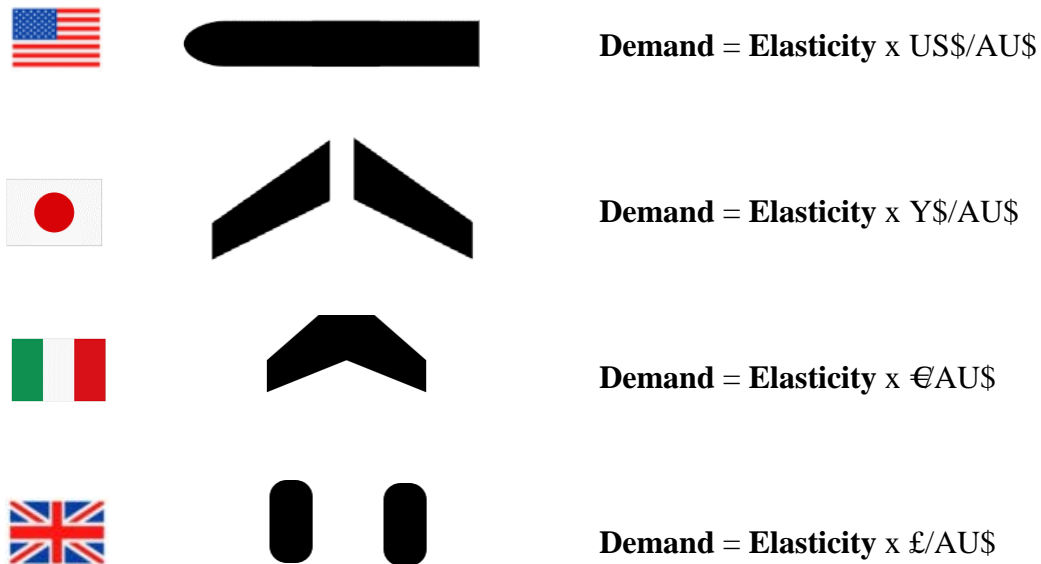
Figure 1. Supply-Chain Flexibility: Which Prices Matter?

The sale of an airplane from the U.S. to Australia

(a) *Inflexible supply chains*: trade is in goods



(b) *Flexible supply chains*: trade is in tasks



Notes: The demand for a Boeing 787 Dreamliner (U.S.) by Qantas (Australia). All figures are for illustrative purposes only. If the supply chain is inflexible, then only the price of the entire finished good matters: trade is in goods. If the supply chain is flexible, then it is as if each component were to be directly exported by each supplier to its final destination: trade is in tasks.

III. A NESTED TEST OF GLOBAL-SUPPLY-CHAIN FLEXIBILITY

In line with the discussion of the previous section, a reduced-form regression that relates relative price changes to the demand for value added should help elucidate the flexible or inflexible nature of global supply chains. The challenge is in adopting a parsimonious specification that nests both possibilities and allows the data to speak for themselves. It is clear from the discussion above that the focus must be placed on value added *exported to final demand*. If we let FVA_{it} and DVA_{it} denote, respectively, foreign and domestic real value added embedded in country i 's exports to final demand at time t , then the following specifications satisfy these requirements:

$$FVA_{it} = \eta + \alpha REER_{it}^* + \beta dva_{it} \times REER_{it} + \gamma fva_{it} \times REER_{it}^* + \delta X_{it} + \varepsilon_{it}, \quad (1)$$

$$DVA_{it} = \eta + \alpha REER_{it} + \beta fva_{it} \times REER_{it}^* + \gamma dva_{it} \times REER_{it} + \delta X_{it} + \varepsilon_{it}, \quad (2)$$

where $REER$ denotes country i 's real effective exchange rate; $REER^*$ denotes the real effective exchange rate of country i 's *intermediate-import partners*; dva (fva) is the share of domestic (foreign) value added in country i 's gross exports to final demand; and X is a vector of controls.⁵

To see how this works, consider for example specification (1) for foreign value added exported to final demand. In the context of our example, in equation (1) country i would be the U.S., $REER$ the U.S. dollar's real effective exchange rate, FVA the value of the Japanese, British and Italian components, and $REER^*$ a weighted average of the real effective exchange rates of these countries. Furthermore, fva (dva) would denote the combined value of the Japanese wings, the British engines and the Italian tail stabilizer (the American main body of the airplane) in ratio to the total value of the airplane.

⁵ The same notation is used across equations (1) and (2), for expositional simplicity given the discussion that follows. Note, however, that the coefficients need not be similar across the two equations, since (as argued below) foreign and domestic value added reflect supply-chain trade to different degrees.

A test of whether global supply chains are flexible is a test of the null hypothesis that $\alpha < 0$ and $\beta = \gamma = 0$. This is because under this assumption, the real effective exchange rates of i 's intermediate-input import partners are the only relevant relative prices. At the other end of the assumption about flexibility, the extreme case of complete inflexibility (Leontief production) is a test of the null that $\alpha = \beta = -\gamma < 0$. To see why, simply note that substituting $\alpha = \beta = -\gamma$ in (1) yields

$$FVA_{it} = \eta + \alpha [fva_{it} \times REER_{it}^* + dva_{it} \times REER_{it}] + \delta X_{it} + \varepsilon_{it}.$$

That is, because of the inflexible production structure, the final good exported is an immutable composite of its different value-added fragments and only the entire price of it faced by the final consumer matters. As a result, the domestic and intermediate-input partners' real effective exchange rates will matter exactly the same when measured in proportion to their value-added contributions.

Of course, the extent of relative production flexibility need not be constant as time passes. In particular, it is plausible that, because of (for example) search frictions or relationship-specific investments, global supply chains are inflexible over short horizons but fully flexible over the longer term. Moreover, the response to changes in relative prices – both in terms of production decisions and with regards to how final demand of a given country's partners react to them – might not be homogeneous across countries over short horizons. Because over the long-run it should be easier for production to relocate, country heterogeneity is far less likely over the long-run. For these reasons, in practice we implement (1) and (2), respectively, as the following error-correction models:

$$\begin{aligned} \Delta FVA_{it} = & \eta_i + \alpha_i \Delta REER_{it}^* + \beta_i \Delta (dva_{it} \times REER_{it}) + \gamma_i \Delta (dva_{it} \times REER_{it}^*) + \delta_i \Delta X_{it} \\ & + \mu_i [FVA_{it-1} - \alpha REER_{it-1}^* + \beta dva_{it-1} \times REER_{it-1} + \gamma dva_{it-1} \times REER_{it-1}^* \\ & - \delta X_{it-1} - \eta] + \varepsilon_{it}, \end{aligned} \quad (3)$$

$$\begin{aligned} \Delta DVA_{it} = & \eta_i + \alpha_i \Delta REER_{it} + \beta_i \Delta (fva_{it} \times REER_{it}^*) + \gamma_i \Delta (fva_{it} \times REER_{it}) + \delta_i \Delta X_{it} \\ & + \mu_i [DVA_{it-1} - \alpha REER_{it-1} + \beta fva_{it-1} \times REER_{it-1}^* + \gamma fva_{it-1} \times REER_{it-1}] \end{aligned}$$

$$-\delta X_{it-1} - \eta] + \varepsilon_{it}. \quad (4)$$

Note, in particular, that all short-run coefficients are allowed to be country-specific, whereas long-run relationships are homogeneous across countries. We estimate (3) and (4) using Pesaran, Shin and Smith's (1999) pooled mean group estimator. By accounting for differences in average behavior of supply chains across countries, country-specific coefficients mitigate concerns that the results gloss over the heterogeneity of such chains.⁶

A word is warranted on the source of variation that we use to identify the degree of flexibility of supply chains: changes in effective exchange rates. It can be instructive to consider the differences between this approach and the other main approach used in the literature, namely the disruption of supply chains due to natural disasters. Papers that exploit disruption from natural events are able to automatically rule out any concerns about endogeneity, a concern we address by using lagged values of effective exchange rates. Focusing on disasters, however, have other limitations. First, studies based on natural disasters are bound to be specific to the country or region that suffers them. Our estimation framework acknowledges the heterogeneity of regional value chains, but at the same time allows us to draw conclusions for the average economy in the world. Second, the shocks associated with these dramatic events are typically transitory. A muted reconfiguration of supply chains in response to a transitory shock is, to some extent, to be expected: agents may simply wait for normal conditions to be restored. Changes in real effective exchange rates, on the other hand, need not be temporary and are often thought of as permanent, or at least extremely long lived. By focusing on the effect of persistent effective exchange rate changes, we are arguably stacking the deck against finding inflexibility, making our results more relevant for other potentially long-lived shocks, such as changes in tariffs.

⁶ See for example Baldwin and Venables (2013) on the heterogeneity of supply chains. At the country level, key differences include whether the product is a standardized component or not, which itself may be linked to where the country is on the global value ladder. Finally, as with most regression models, our linear specification assumes that responses are proportional to the size of the shock.

IV. DATA: SOURCES AND OVERVIEW

A. Data sources

Data on foreign and domestic value added embedded in gross exports destined to final demand are available from the OECD TiVA database.⁷ The latest OECD TiVA edition spans 2005-2015. We splice these latest series with the 1995-2005 data available in the previous edition of the TiVA database. Note that these data include trade in services as well as goods, which is useful because services are often thought of as important for global supply chains (IMF-WB-WTO, 2018).

To deflate the series, which are originally expressed in nominal U.S. dollars, country-level deflators must be constructed. To the best of our knowledge, no deflators for input-output tables exist. The choice among available deflators can be thought of as involving a tradeoff between adequately representing the composition of goods exported, and their origin. Our baseline results are based on using export deflators. This choice is guided by the fact that, on average, *three-quarters* of gross exports represent exports of domestic value added. In comparison, the alternative of using GDP deflators would face the issue that these include a heavy services component (reflecting the importance of services sectors in countries' GDPs) but services comprise *less than one-half* of trade in value-added terms (Johnson, 2014).⁸ All data on deflators are from the World Economic Outlook database.

For foreign value added embedded in country i 's exports to final demand, the deflator is a weighted average of country i 's partners' deflators. Rather than basing our weights on

⁷ For example, using the OECD TiVA nomenclature, $FVA = EXGR_FNL - (EXGR \times EXGR_FNLDVASH)$, where $EXGR_FNL$ are gross exports of final demand goods, $EXGR$ are gross exports, and $EXGR_FNLDVASH$ is the domestic value added in exports of final demand products as a share of total gross exports. We exclude the four large oil exporters available in TiVA (Bahrain, Norway, Russia and Saudi Arabia). This leaves us with a sample of 59 economies: Argentina, Australia, Austria, Belgium, Bulgaria, Brazil, Canada, Switzerland, Chile, China, Colombia, Costa Rica, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, the UK, Greece, Hong Kong SAR, Croatia, Hungary, Indonesia, India, Ireland, Iceland, Israel, Italy, Japan, Cambodia, Korea, Lithuania, Luxembourg, Latvia, Morocco, Mexico, Malta, Malaysia, the Netherlands, New Zealand, Peru, Philippines, Poland, Portugal, Romania, Singapore, Slovakia, Slovenia, Sweden, Thailand, Tunisia, Turkey, Taiwan P.O.C., the U.S., Vietnam and South Africa.

⁸ For completeness, Table A1 in the Annex compares our baseline estimates (based on export deflators) to those obtained using GDP deflators. Unsurprisingly, under this alternative specification some coefficients have the wrong sign.

countries' import of intermediates, we account for the fact the intermediates may themselves embed value added by countries further up the value chain. That is, our weights are based on direct and indirect input requirements. Following a standard input-output procedure, let \mathbf{X} denote the matrix with element x_{ij} equal to sales of intermediates from country i to country j , in ratio to total purchases of intermediates by country j . Intermediate-input requirements are then given by the elements in matrix $\mathbf{W} = (\mathbf{I} - \mathbf{X})^{-1}$, where \mathbf{I} is the identity matrix.⁹ Our weights are given by re-normalizing the non-diagonal elements of \mathbf{W} to add up to one.¹⁰

These and all other weights based on trade data are based on 3-year rolling windows, with the exception of the first two years in the sample (1995 and 1996) for which we use (respectively) one- and two-year windows. Data on intermediate-input trade are from the OECD Inter-Country Input-Output Tables.

Turning to the key dependent variable, we use real effective exchange rates from the IMF INS database. Besides the exporting country's REER, we also use as explanatory variable the weighted REER of the exporting country's trading partners. As with foreign value added deflators, weights are calculated based on direct and indirect input requirements. Note that, in principle, one could perform our tests adapting the real effective exchange rate to accommodate the production structure assumed under the null hypothesis. That is, for example, when testing the hypothesis that supply chains are inflexible we could use a real effective exchange rate constructed with weights derived assuming Leontief production. As the in-depth analysis in Bayoumi et al. (2018) reveals, over the historical period there is little difference between the IMF rates and those calculated using different production structures.¹¹

⁹ Recall from basic input-output algebra that the matrix $(\mathbf{I} - \mathbf{X})^{-1}$ solves $\mathbf{GO} = (\mathbf{I} - \mathbf{X})^{-1}\mathbf{F}$, where \mathbf{GO} stands for gross output and \mathbf{F} stands for final demand. Insofar as all countries add value, matrix \mathbf{X} is column sub-stochastic. This means that the spectral radius of \mathbf{X} is below unity and therefore the inverse of $(\mathbf{I} - \mathbf{X})$ always exists.

¹⁰ We exclude the rest of the world, as we do not have a deflator for this residual entity. We also exclude Kazakhstan, since it is not included as a separate country in the earlier vintage (1995-2004) of the OECD database.

¹¹ Concisely put, the central point is that moving toward REERs that account for trade in intermediates raises the importance of the U.S. (the world's leading final consumer) at the expense of China (the world's factory). Since the value of the U.S. dollar and the renminbi have been closely related in the historical data, this shift in weights is of little consequence. In unreported results we take the different REER measures provided by Bems

Finally, we include three controls in all our regressions. Foreign demand is measured as an export-weighted average of partners' real GDPs. Again, to be consistent with our framework, in this case the trade weights are based on final-goods exports. Real GDP data are from the World Economic Outlook database, and final-goods exports are from the OECD Inter-Country Input-Output tables. Lastly, we include an index of oil prices and an index of non-fuel commodity prices, both from the World Economic Outlook database.

With the exception of domestic and foreign value added shares, variables are measured in natural logarithms. As is customary, to mitigate endogeneity concerns real effective exchange rates and their interaction terms are measured with a one-period lag with respect to the left-hand-side variables.

B. An overview of the data: The changing structure of international trade

To set the stage, it is useful to provide some background on the changing nature of global trade underlying our data. The global input-output tables can be used to create a summary of trade across our sample (which covers over 90 percent of global output).

We can divide gross trade into trade in domestic value added and foreign value added (Figure 2a). The proportion of trade represented by foreign value added is a measure of the depth of supply chains, since it measures the use of foreign components in overall trade. For the 63 economies in our data set, gross trade rose from 16½ percent of GDP in 1995 to peak at 23½ percent in 2008 before giving up about a quarter of these gains and falling to 21½ percent in 2015. Trade in domestic value added, which excluded trade in foreign goods and is the correct concept of openness since GDP measures domestic value added, fluctuated by significantly less, rising by only about half the value of gross trade (from 14 percent of GDP in 1995 to a peak of 18 percent in 2008) before also falling back more modestly to 17 percent of GDP in 2015. This implies a major deepening of supply chains up, particularly from the early 2000s to the global financial crisis in 2008, plausibly connected to the entry of China

and Johnson (2017), which cover a shorter sample than the one used in this paper (1995-2011). Unsurprisingly, elasticity estimates are virtually unaltered as we rotate the REER measure.

into the World Trade Organization, followed by a modest decline thereafter. Further analysis reveals that the cause of the post-2008 decline was partly driven by China's switch to relying on domestic rather than external demand as foreign markets became saturated and Chinese goods moved up the global value ladder thanks to technology upgrading. Excluding China, trade openness measured either using gross trade or domestic value added flat-lined after the global crisis (Figure 2b) suggesting that the forces for trade integration and deeper supply chains were offset by rising protectionism.

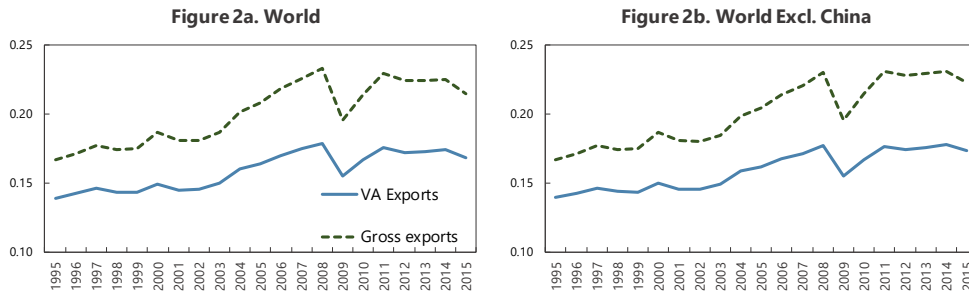
Analysis of countries deeply involved in supply chains suggests that these regions continued to become more open and their supply chains continues to deepen after 2008, although at a somewhat slower pace than in the past, particularly for intermediate goods (Figure 3). For example, in the central and eastern European supply chain centered on Germany, which includes Poland, the Czech Republic, Slovakia, Hungary, Bulgaria, Romania, and the three Baltic states, value added (gross) exports rose from 16½ (19½) percent of GDP in 1995 to 25½ (35) percent in 2008, and rose again to 28 (38) percent in 2015. Similarly, the Asian supply chain anchored by Japan and China and including Hong Kong SAR, Korea, Singapore, Taiwan Province of China, Thailand, Malaysia, Thailand, Cambodia, and Vietnam also continued to become more open and deeper after 2008 once China is excluded. Interestingly, the export openness and role of foreign goods in the initial 12 Euro area members (excluding Germany), which had been relatively moribund from 1995 to 2008, accelerated markedly after 2008. By contrast, the export openness and supply chains of the North American region (the US, Canada, and Mexico) and the remaining countries in Europe (UK, Sweden, Denmark, Croatia, Cyprus, and Malta) stagnated.

Offsetting these gains in openness of supply chains and the euro area after the financial crisis was a marked fall in openness of the rest of the world. This group, comprising oil exporters (Norway, Saudi Arabia, Russia, and Bahrain), commodity exporters (Australia, Chile, Columbia, and Peru), together with Argentina, Brazil, Costa Rica, Iceland, Indonesia, India, Israel, Morocco, New Zealand, the Philippines, South Africa, Tunisia, and Turkey, whose value added (gross) export openness had risen from 13 (14½) percent of GDP in 1995 to 18 (21½) percent by 2008, saw a significant part of these gains erased by 2015.

The evolution of the global economy in terms of supply chains can be summarized by examining value-added trade and trade in final goods as a ratio of gross trade for individual economies (Figure 4). The former (on the vertical axis) measures of how important domestic goods are in a countries trade while the latter (on the horizontal axis) measures the role of final assembly in trade. In 2015, countries such as Slovakia, Mexico, and Vietnam, which specialize in final assembly, are in the bottom righthand corner, with a low ratio of domestic goods but a high ratio of final goods in their trade. In the bottom middle are economies in the center of the supply chain, with a high ratio of foreign goods but not specializing in final assembly, such as Korea, Taiwan Province of China, Malaysia, Thailand, Hungary, the Czech Republic, Bulgaria, and Estonia. The upper middle area, with high domestic value added but middling final goods exports, includes the hubs of the value chains—Germany, China, Japan, and the United States—as well as some parts of the rest of the world, such as Brazil, Israel, and India. In the upper left corner, with high domestic value added but low ratios of final goods, are commodity producers, most notably Saudi Arabia and Bahrain, but also Chile, Peru, Russia, and some hybrid economies which mix commodity and manufactured exports, such as Canada and South Africa.

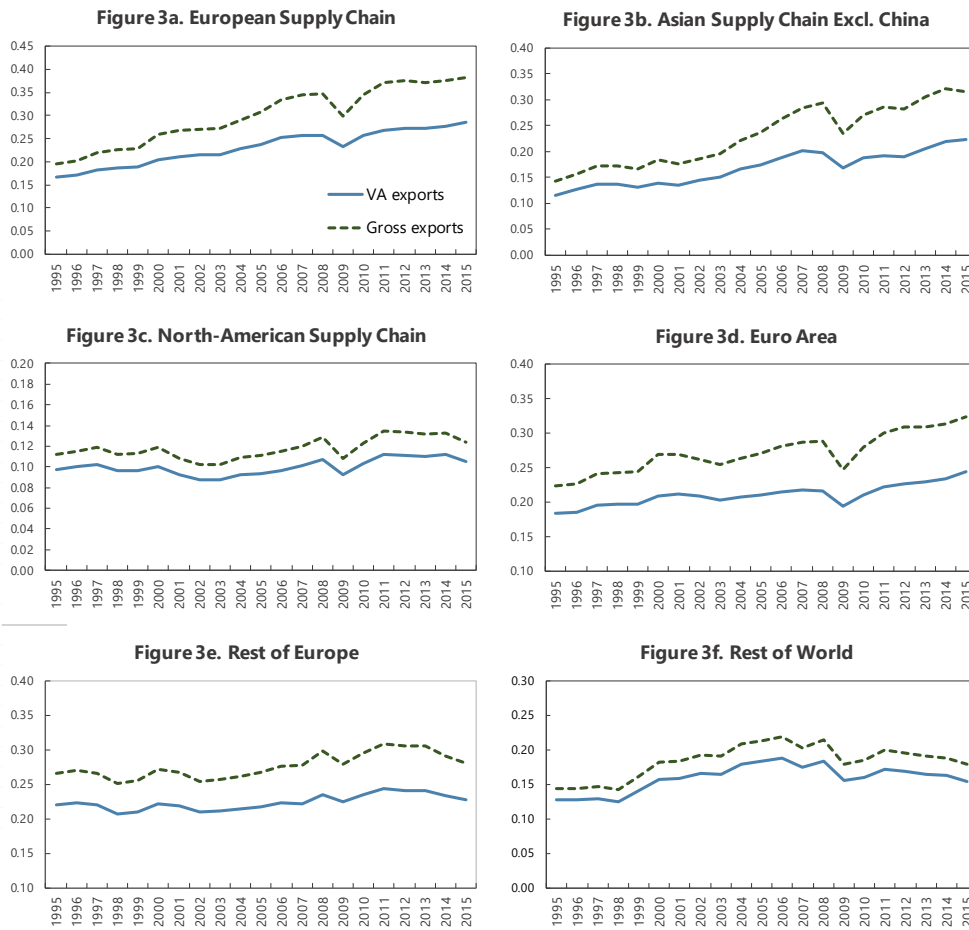
These value chains have evolved over time. In 1995 they were relatively embryonic, before growing rapidly (in part reflecting the entry of China into the World Trade Organization in 2001) and reaching a zenith in 2008. As can be seen, the data for 1995 (Figure 5a) shows considerably less differentiation in final goods production than in 2015 suggesting much less defined supply chains, while the equivalent graph for 2008 (Figure 5b) features a much clearer downward sloping line than in 2015, suggesting better defined supply chains. There are also some interesting changes in the positions of economies over time. For example, between 2008 and 2015 Hungary moves from being assemblers of final goods to the middle of the European supply chain with a similar (if less dramatic) shift for China in the Asian chain, while Slovakia and Mexico make the opposite journey in becoming more focused on final assembly (Figures A1-A18 in the Appendix show the data for individual supply chains and for the rest of the world for 1995, 2008, and 2015).

Figure 2. World's Export Openness



Notes: *VA Exports* refers to the domestic value a given country (group) adds to its exports, while *Gross Exports* includes both the domestic contribution and value previously added by foreigners. Both variables are in ratio to nominal GDP.

Figure 3. Export Openness by Region



Notes: See notes to Figure 2.

Figure 4. Global Value Chains in 2015

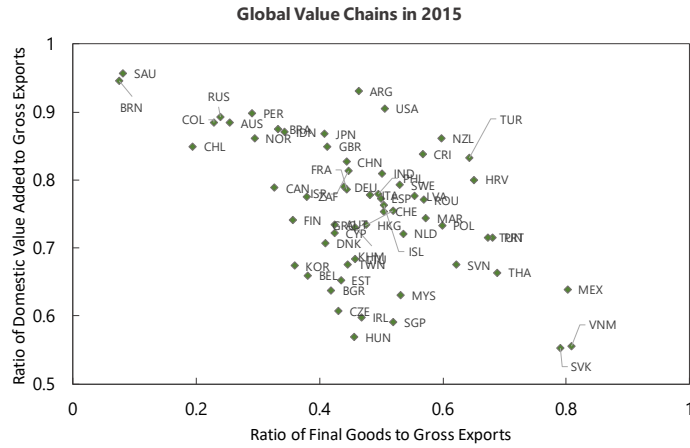


Figure 5. Global Value Chains in 1995 and 2008

Figure 4a. Global Value Chains in 1995

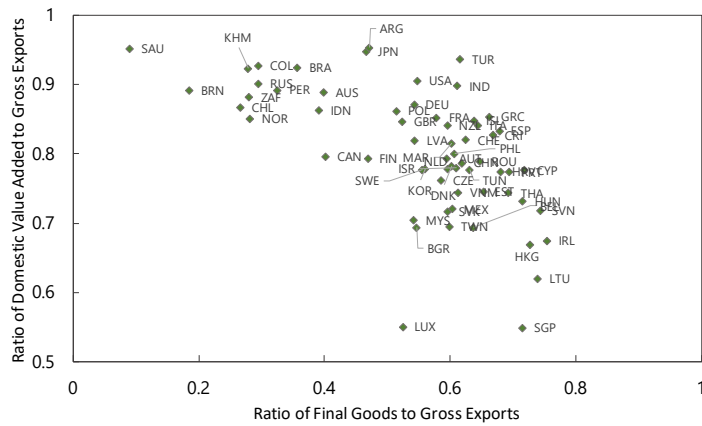
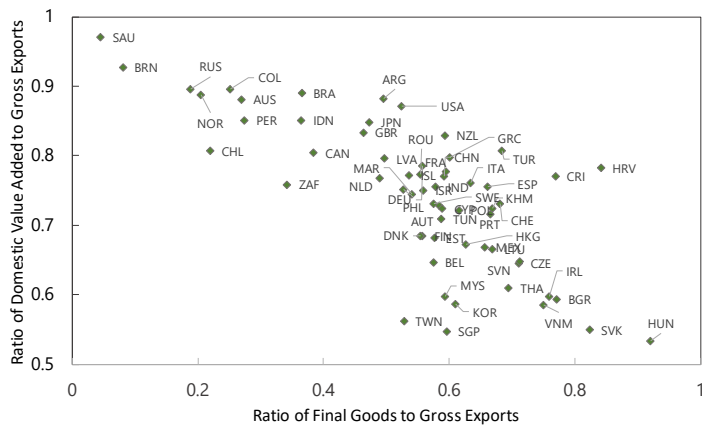


Figure 4b. Global Value Chains in 2008



V. RESULTS

A. Baseline results

Tables 1 and 2 present our baseline estimates for the foreign and domestic value-added equations. The top part of each table shows the long-run coefficient estimates, whereas the bottom half presents the estimates associated with the short-run dynamics. To facilitate the interpretation of the results, the first two columns in the table show the expected coefficients if the data generating process were a world of flexible supply chains (column (1)) and a world where global supply chains are fully inflexible (column (2)). Consider, for example, the case of foreign value added. Recall from Section 4 that if supply chains are flexible, then the only relevant relative price is be the importing partners' effective exchange rate. The coefficient associated with this relative price should thus be negative under this hypothesis, and the two interaction terms should not be significant. Under the extreme case of Leontief (i.e. fully inflexible) supply chains, all three coefficients should be equal in absolute terms, with the coefficient associated with the interaction of partners' exchange rates and the domestic value-added share being positive.

Our estimates based on the full (1995-2015) sample are presented in column (3) of Tables 1 and 2. The estimated error correction term is highly significant in both equations, suggesting that there is a cointegrating relationship and therefore an error-correction model is the correct specification. The estimated speed of adjustment implies a half-life for deviations from the long-run relationships of about 3 years for the foreign value-added equation, and 4 years for the case of domestic value added.¹² Closing three-quarters of any short-run deviation requires between 8 and 9 years. In all, the estimated speed of adjustment suggests that the short-run coefficients remain relevant even for horizons of 5 years.

Estimated coefficients associated with our three controls generally have the expected sign. Foreign demand increases exports of foreign and domestic value added, both in the short- and in the long-run. Higher commodity prices appear to mostly act as a negative supply shock in the exports of domestic value added, entering with a negative sign in our baseline

¹² Recall that $\mu < 0$ denotes the speed-of-adjustment parameter. The half-life ξ thus solves $(1 + \mu)^\xi = 1/2$.

results for DVA (the exception is the effect of non-fuel commodity prices in the long-run equation). We had no priors on the sign of the commodity-price variables in the foreign value-added equation; the results suggest they positively affect these exports.¹³

The evidence presented in Tables 1 and 2 overwhelmingly rejects the hypothesis that global supply chains are flexible, not just in the short run but also in the long run. In the short run, the interaction terms are highly significant in the foreign value-added equation. Estimates are obtained with relatively less precision in the domestic value-added equation. This is to be expected: while foreign value added is by definition trade involved in a global supply chain (insofar it measures exports of intermediates that are further processed to be re-exported), domestic value-added exports include also exports that need not be part of a multi-country supply chain.

A rough estimate of a plausible range for the degree of inflexibility in the supply chains can be calculated by dividing the exchange rate coefficients associated with the two interaction terms (the *dva* and *fva* terms) by the estimate of the exchange rate elasticity for all trade. For the foreign value added equation in the short term this implies a coefficient of between $\frac{3}{4}$ and 1 (more precisely, from 0.477/0.64 to 0.677/0.64, although a formal test that trade is fully inflexible is rejected).¹⁴ The equivalent coefficients in the domestic value added equation are above 1, but much less well estimated (in this case, a formal test does not reject that the supply chain is fully inflexible).

The results in Tables 1 and 2 suggest not only that in the short run supply chains have some degree of inflexibility, but that – using the entire sample – they are not far from the extreme case of a Leontief structure. Qualitatively, the departure from the case of fully inflexible

¹³ These positive estimated coefficients in the FVA equation might be controlling for the fact that, as discussed above, our deflators do not account for the part of a country's exports that correspond to value added by other countries, e.g. commodity exporters. By virtue of representing less-finished products, our FVA series will have a larger share of commodities embedded in them than our DVA series. As a result, any potential deflator correction because of commodity prices is necessarily more important in the FVA than in the DVA equation.

¹⁴ Appendix B includes a formal derivation based on our estimates. The corollary is that, if one were to think of a world with a mixture of one fully flexible and one fully inflexible good, our estimates imply that the contribution of the inflexible good to global supply chains in the short run is of *at least* 60 percent.

supply chains is in the direction one would expect: in both equations, the currency of the country where the value added originates plays a slightly outsized role when compared to its value-added contribution to the finished final good.

Surprisingly, supply chains remain somewhat inflexible even in the long run. In particular, while the longer horizon leads to larger elasticities overall (i.e. estimated coefficients tend to be larger in absolute value), complementarities in production persist. All long-run point estimates have the expected sign, and the fact that there is significance of some of the interaction terms in both equations reveals a degree of inflexibility in production even over long horizons. Using the same approach discussed above, the estimated coefficient of inflexibility is $\frac{1}{4}$ to $\frac{1}{2}$ for the foreign valued equation and $\frac{2}{3}$ to 1 for the domestic value-added equation. In other words, expenditure decisions at the production stage remain less flexible to price changes than final-demand expenditure decisions even in the long-run.

The previous section noted the acceleration in the growth of supply chains since the early 2000s. If this structural break is indeed a reflection of qualitative changes in the type of intermediates that are being traded, with an increasing prevalence of complex goods over easy-to-substitute commodities, then the overall degree of flexibility should fall in the data. In fact, short-run responses of supply chains appear to have become increasingly inflexible over time as supply chains have deepened.

Re-estimating the model over different subsamples (removing, alternatively, the last and first five years of the sample) reveals that production linkages might have become fully inflexible in the short run more recently (columns (4) and (5) in Tables 1 and 2).¹⁵ In particular, while the hypothesis that the supply chain is completely inflexible in the short-term ($\alpha = \beta = -\gamma$) is rejected in the 1995-2010 sample in both equations (Wald test p-values of 0.0001 and 0.0152 in the FVA and the DVA equations, respectively) it cannot be rejected in either the foreign or the domestic value-added equations over the 2000-2015 sample (Wald-test p-

¹⁵ While we tried to estimate the model over the first and second half of the sample, the samples proved too short for the maximum likelihood estimator to produce results so we opted for taking off five years off at the end and the start of the sample.

values of 0.87 and 0.13, respectively). This suggests that the observed rising share of foreign inputs in international trade (Figure 2) is due to the development of increasingly complex production chains that involve more specialized inputs. Strikingly, the long-run elasticities imply a relatively inflexible supply chain even in the long-run, at least in the more reliable foreign value-added equation.

Table 1. Estimation Results - Foreign Value Added (FVA)

	(1)	(2)	(3)	(4)	(5)
	Theory			Empirics	
	<i>Flexible supply chains</i>	<i>Leontief supply chains</i>	<i>Baseline (1995-2015)</i>	<i>1995-2010</i>	<i>2000-2015</i>
LONG RUN					
Importing partners' EER	-A	-B	-2.252 (-5.45)***	-2.814 (-5.75)***	-0.991 (-6.71)***
Own EER x DVA share	0	-B	-0.607 (-4.60)***	-0.615 (-3.81)***	0.0618 (0.87)
Importing partners' EER x DVA share	0	+B	1.295 (5.07)***	1.810 (4.97)***	-0.605 (-5.60)***
Foreign demand			0.170 (1.51)	-0.741 (-3.11)***	0.408 (4.37)***
Oil price			0.156 (3.89)***	0.352 (5.26)***	-0.0243 (-0.82)
Non-fuel commodity price			0.262 (4.28)***	0.609 (6.43)***	0.301 (7.21)***
SHORT RUN					
Error-correction term			-0.202 (-7.10)***	-0.216 (-7.31)***	-0.292 (-5.18)***
Importing partners' EER	-a	-b	-0.640 (-2.94)***	-0.703 (-2.21)**	-0.290 (-1.00)
Own EER x DVA share	0	-b	-0.477 (-4.43)***	-0.516 (-2.02)**	-0.442 (-2.88)***
Importing partners' EER x DVA share	0	+b	0.677 (5.56)***	0.804 (2.87)***	0.456 (2.61)***
Foreign demand			3.227 (12.23)***	2.502 (5.06)***	3.586 (12.30)***
Oil price			0.00901 (0.43)	0.0448 (1.72)*	0.0541 (2.53)**
Non-fuel commodity price			0.124 (2.58)***	0.230 (2.44)**	0.0117 (0.21)
Constant			1.899 (7.03)***	2.620 (7.45)***	2.079 (4.93)***
N			1,116	822	944

t statistics in parentheses

* p<0.1 ** p<0.05 *** p<0.01

Table 2. Estimation Results - Domestic Value Added (DVA)

	(1)	(2)	(3)	(4)	(5)
	Theory			Empirics	
	<i>Flexible supply chains</i>	<i>Leontief supply chains</i>	<i>Baseline (1995-2015)</i>	<i>1995-2010 \1</i>	<i>2000-2015</i>
LONG RUN					
Own EER	-A	-B	-0.750 (-6.34)***	-1.439 (-13.75)***	-2.574 (-11.03)***
Importing partners' EER x FVA share	0	-B	-0.435 (-0.75)	-5.665 (-10.63)***	-7.665 (-9.30)***
Own EER x FVA share	0	+B	1.381 (2.31)**	5.288 (10.25)***	8.521 (10.80)***
Foreign demand			0.455 (3.80)***	1.287 (15.86)***	1.506 (9.15)***
Oil price			-0.0728 (-2.31)**	-0.0688 (-4.16)***	-0.0407 (-0.84)
Non-fuel commodity price			0.204 (6.08)***	0.237 (14.18)***	0.0432 (0.71)
SHORT RUN					
Error-correction term			-0.155 (-6.49)***	-0.246 (-5.30)***	-0.156 (-5.50)***
Own EER	-a	-b	-0.297 (-1.54)	-0.296 (-1.38)	-0.495 (-2.07)**
Importing partners' EER x FVA share	0	-b	-0.719 (-1.01)	-0.924 (-0.97)	-1.900 (-2.14)**
Own EER x FVA share	0	+b	0.757 (1.05)	0.806 (0.82)	1.950 (2.16)**
Foreign demand			2.174 (12.84)***	2.309 (6.72)***	2.108 (10.48)***
Oil price			-0.0769 (-5.55)***	-0.0947 (-4.20)***	-0.0467 (-3.27)***
Non-fuel commodity price			-0.0105 (-0.29)	0.0174 (0.29)	-0.0278 (-0.78)
Constant			0.741 (5.39)***	1.162 (5.47)***	1.309 (5.58)***
N			1,116	821	944

t statistics in parentheses

* p<0.1 ** p<0.05 *** p<0.01

B. Dominant currency paradigm

Recent research raised the possibility that, given the prevalence of dollar invoicing in international trade, bilateral dollar exchange rates are the key relative price to understand trade-flow dynamics. This has come to be known as the Dominant Currency Paradigm (DCP). Evidence to this end has been found, inter alia, in the context of bilateral trade regressions (Boz, Gopinath and Plagborg-Møller, 2018) and using micro-data from customs in Colombia (Casas, Diez, Gopinath and Gourinchas, 2017).

Given this possibility, in this subsection we analyze whether our conclusions are robust to the choice of effective exchange rate. In doing so, it should be clear that we do not intend to test the validity of the DCP hypothesis, something that would be outside the scope of this paper and for which bilateral trade data are better suited. Rather, we take the DCP hypothesis as given and analyze whether our conclusions regarding the degree of flexibility in global supply chains carry through when an alternative price measure is used.¹⁶

We thus re-estimate our baseline specification but using effective exchange rates constructed to account for the U.S. dollar's outside role in trade invoicing. Specifically, instead of the effective exchange rate measure used in our baseline results, for all countries other than the U.S. we use an effective exchange rate defined as follows:

$$\widehat{REER}_{it} \equiv v_i RER_{it}^{US} + (1 - v_i) REER_{it}^{-US},$$

where v_i is the share of trade invoiced in U.S. dollars, RER_{it}^{US} is the bilateral real exchange rate vis-à-vis the U.S., and $REER_{it}^{-US}$ is the real effective exchange rate with its weights recalculated to as to exclude the U.S.¹⁷

¹⁶ In unreported results that are available upon request, we also estimated a model including both our baseline REER and the DCP-derived effective exchange rate presented below. Given a high degree of collinearity, coefficients were estimated only very imprecisely. To facilitate comparisons, we also tried to estimate our baseline specification but restricting the sample to those countries for which a DCP-based effective exchange rate can be constructed. Unfortunately, the maximum likelihood estimator failed to converge.

¹⁷ The U.S. is excluded from the DCP sample.

Country-level data on the share of trade invoiced in U.S. dollar are taken from Gopinath (2016). When constructing the own effective exchange rates, we take v_i to be equal to the simple average of export and import dollar invoicing. For the import-weighted partner effective exchange rates, we set each partner's v_i to be equal to their share of exports invoiced in dollars.¹⁸

The results using this alternative exchange-rate measure are presented in Table 3. Despite the substantially-smaller sample, driven by availability of invoicing data, our conclusions prove robust to using the modified effective exchange rate. All estimates remain significant in the foreign value-added equation (Table 3, column (2)), whereas the significance of the interaction terms increases in the case of domestic value added (Table 3, column (4)). In the foreign value-added equation, in the smaller sample the estimated speed of adjustment is substantially lower and foreign demand enters with the wrong sign. Overall, however, the evidence clearly points to the inflexibility of supply chains.

¹⁸ It may worth noting that v_i is time-invariant, as dollar-invoicing shares in Gopinath (2016) correspond to a single point in time. To the best of our knowledge, no comprehensive time-series data on dollar invoicing exists. Moreover, the invoicing data are not available for the following jurisdictions that are included in the sample that yields our baseline results: Chile, China, Costa Rica, Hong Kong SAR, Croatia, Cambodia, Morocco, Mexico, Malta, Malaysia, New Zealand, Peru, Philippines, Singapore, Tunisia, Taiwan POC, Vietnam and South Africa.

Table 3. Dominant currency paradigm

	(1)	(2)	(3)	(4)
	FVA		DVA	
	Baseline	DCP	Baseline	DCP
LONG RUN				
Importing partners' EER	-2.252 (-5.45)***	-3.406 (-2.23)**		
Own EER x DVA share	-0.607 (-4.60)***	-1.429 (-3.18)***		
Importing partners' EER x DVA	1.295 (5.07)***	6.231 (3.52)***		
Own EER			-0.750 (-6.34)***	-0.734 (-5.93)***
Importing partners' EER x FVA			-0.435 (-0.75)	-1.136 (-1.85)*
Own EER x FVA share			1.381 (2.31)**	2.102 (3.45)***
Foreign demand	0.170 (1.51)	-2.34 (-2.27)**	0.455 (3.80)***	0.351 (2.59)***
Oil price	0.156 (3.89)***	1.307 (3.87)***	-0.0728 (-2.31)**	-0.071 (-2.21)**
Non-fuel commodity price	0.262 (4.28)***	0.339 (1.00)	0.204 (6.08)***	0.27 (6.38)***
SHORT RUN				
Error-correction term	-0.202 (-7.10)***	-0.0702 (-5.90)***	-0.155 (-6.49)***	-0.169 (-5.14)***
Importing partners' EER	-0.640 (-2.94)***	-0.828 (-2.78)***		
Own EER x DVA share	-0.477 (-4.43)***	-0.404 (-3.08)***		
Importing partners' EER x DVA	0.677 (5.56)***	0.754 (5.41)***		
Own EER			-0.297 (-1.54)	-0.184 (-1.54)
Importing partners' EER x FVA			-0.719 (-1.01)	-0.82 (-1.28)
Own EER x FVA share			0.757 (1.05)	0.886 (1.33)
Foreign demand	3.227 (12.23)***	3.375 (11.33)***	2.174 (12.84)***	2.167 (10.64)***
Oil price	0.00901 (0.43)	0.0387 (1.40)	-0.0769 (-5.55)***	-0.089 (-4.42)***
Non-fuel commodity price	0.124 (2.58)***	0.058 (0.93)	-0.0105 (-0.29)	0.0206 (0.48)
Constant	1.899 (7.03)***	0.458 (6.45)***	0.741 (5.39)***	0.873 (4.40)***
N	1,116	760	1,116	760

t statistics in parentheses

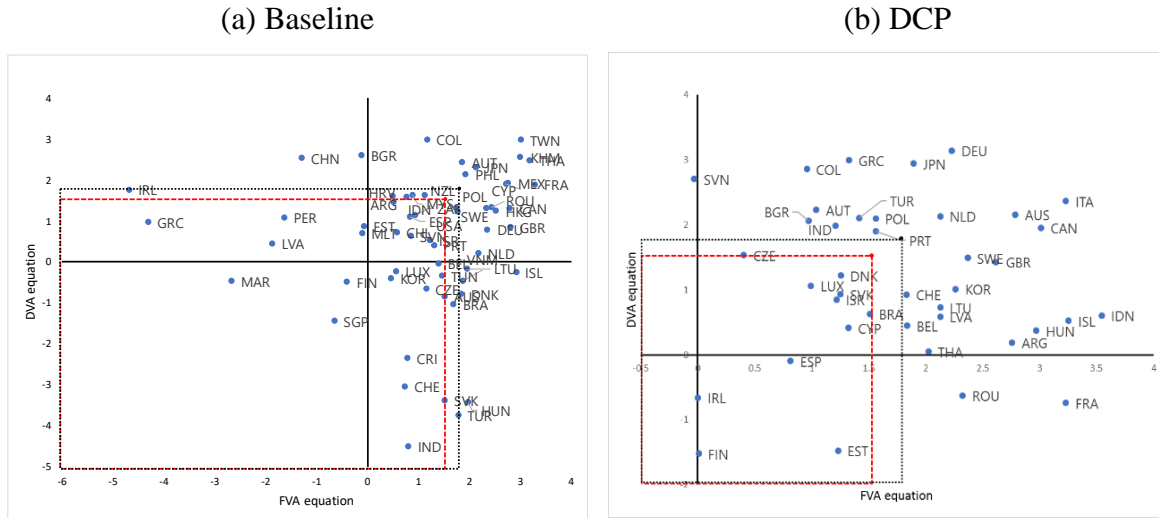
* p<0.1 ** p<0.05 *** p<0.01

C. Country-level evidence of production complementarities

The pooled-mean-group estimator we use can also shed light on whether complementarities in production are strong in the short run for any given country. While the time dimension in our sample is relatively small (21 years) compared to the number of regressors, it is worth analyzing whether the data still reveal any evidence on production complementarities at the country level.

While the number of estimated coefficients is very large, one possible approach to summarize the information is to compute, for each country and each value-added component, the statistic for the test that has as null hypothesis the assumption of no production complementarities – i.e. $\beta = \gamma = 0$. Figure 6 (a) shows the resulting statistics coming out of our baseline results. The statistic for the foreign value-added equation is measured on the horizontal axis; the statistic for the domestic value added equation is measured on the vertical axis. Black and red dotted lines delimit, respectively, 0.05 and 0.1 significance levels.

Complementarities in production appear to be strong enough in many countries to overcome the intrinsic imprecision stemming from the short time span used to obtain these estimates. This is the case of many economies in the Asian supply chain, such as Thailand and Taiwan POC; countries in the North American chain (Mexico and Canada); and some European countries (such a France). Notably, it includes all of the supply-chain hubs: China, Japan, Germany, and the United States. For completeness, Figure 6 (b) performs the same exercise but using our alternative, DCP-based effective exchange rate measure, leading to the same overarching conclusion.

Figure 6. Complementarities in production: country-level evidence

Notes: Statistics for the test $H_0: \beta = \gamma = 0$ (no production complementarities), in log scale. Black dotted line delimits 0.05 significance; red dotted line delimits 0.10 significance.

VI. IMPLICATIONS FOR TRADE AND ECONOMIC ACTIVITY

Our estimates can be used to calculate the effect of changes in a country's real effective exchange rate on its exports. In particular, the system of equations (3)-(4) for countries $i = 1, \dots, N$ can be used to trace the effect of REER movements on the different parts that make up a country's gross exports.

This is illustrated in Figure 7, where we decompose a country's gross exports and map each component to the corresponding set of equations that should be used to trace the effects of REER changes. Let i denote the country of interest. The case of final goods exports is straightforward. The estimated coefficients of equations (3) and (4), together with the domestic value added share dva_{it} (and of course setting to zero the change in partners' real effective exchange rates, $REER_{it}^*$), suffice to get the estimated impact on domestic and foreign value added embedded in i 's exports of final goods.

The issue is only slightly more involved for the case of i 's exports of intermediates. These exports by i go into the production processes of i 's partners. When i 's partners, in turn,

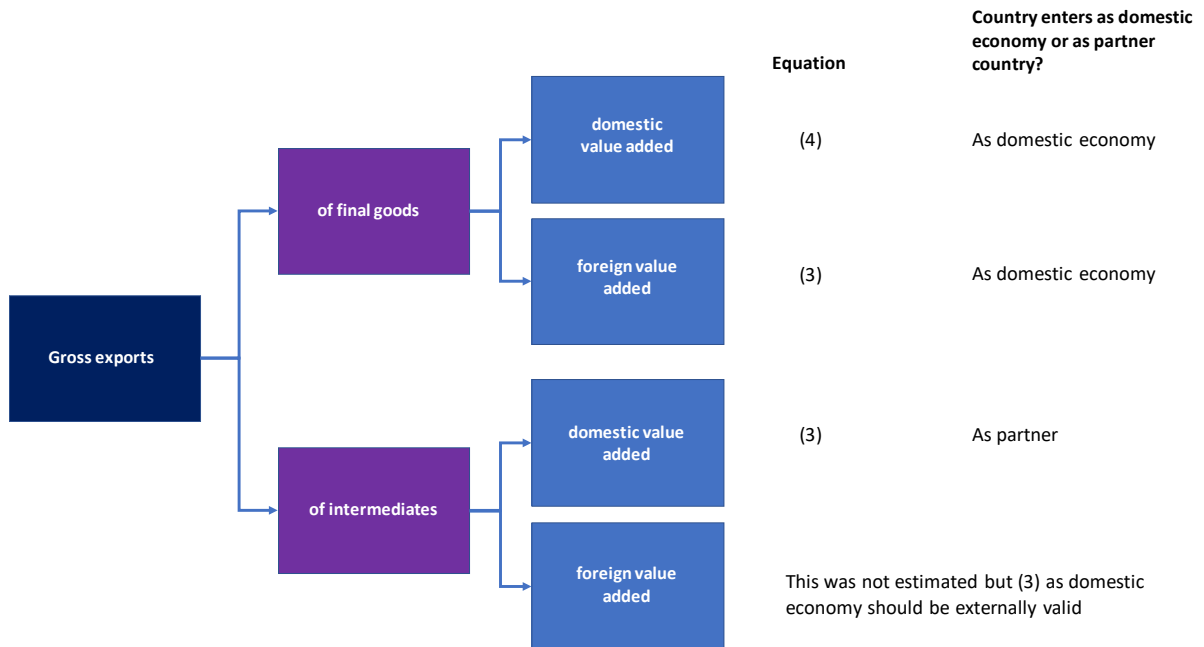
embed this value added into their final goods exports, then it will be picked up by equation (3) for each country $j \neq i$, where the change in i 's exchange rate is represented by $REER_{jt}^*$. As highlighted in Figure 7, we have not directly estimated an equation for foreign value added embedded in exports of intermediates. We argue, however, that equation (3) should be externally valid in this context.¹⁹

Consider, for example, the short-run response of i 's intermediates exports to a change in i 's REER of magnitude Δ_i . If ω_{ij} denotes the share of j 's imports of intermediates that originate from i , then the short-run response would be

$$\Delta_i \times \sum_{j \neq i} \omega_{ij} (\alpha_i + \gamma_i dva_{it}), \quad (5)$$

where the coefficients α_i and γ_i correspond to those in equation (3).

Figure 7. Mapping Estimates to Different Components of a Country's Gross Exports



¹⁹ It is a priori unclear whether exports of intermediates that are processed and re-exported as intermediates should be expected to be more or less substitutable than those that are re-exported to final demand. On the one hand, longer global supply chains may involve more complex transformations of goods, thus pointing to possibly-lower elasticities. At the same time, goods that correspond to the initial stages of the production process may tend to be more substitutable, as is the case e.g. of raw materials.

Of particular interest to policy makers is the potential response of domestic value-added exports to fluctuations in the REER. This can be obtained using equation (4) and expression (5). To see how this would be operationalized for the average country in our sample, first note that on average in the sample $\overline{dva} = 0.75$ and that, in the cross-section, exports of intermediates represent 58 percent of total exports. In the short-run, therefore, the average country's value-added exports' response to a one percentage point depreciation is estimated as²⁰

$$(-1) \times \left[\underbrace{(-0.297 + 0.25 \times 0.757)}_{DVA \text{ in final demand exports}} \times 0.42 + \underbrace{(-0.640 + 0.75 \times 0.677)}_{DVA \text{ in intermediate exports}} \times 0.58 \right] = 0.12.$$

It should be clear from these calculations how complementarities in production temper the effect of depreciations. Our point estimates imply that, in response to a one percentage point REER depreciation, domestic value-added exports destined to final demand would increase by 0.11 percent, and domestic value added exported as intermediates would increase by 0.13 percent. In all, the percent increase in total value-added exports implied by our estimates in response to a one percentage point depreciation is 0.12. Note, however, that overall openness has been rising over time even when correctly measured as domestic value-added content. This implies that the impact of exchange rate changes on output has been rising, even as the development of supply chains has tempered the impact of exchange rate on gross trade.

VII. CONCLUDING REMARKS

The rise of global supply chains has had profound effects on individual economies and the global trading system, also complicating standard macroeconomic analyses. For many of the new and challenging questions brought about by this phenomenon, the answer largely depends on one specific aspect of global value chains: how easily they can re-configure in response to changes in prices. In this paper, we proposed a parsimonious specification to test

²⁰ Since the calculation is for the average country, the weights ω_{ij} from expression (5) do not show up in this expression.

the degree of global-supply-chain flexibility. Our estimates show that, in the short run, the production structure is very inflexible, and that this inflexibility has risen over time as supply chains have deepened. Indeed, for the 2000-15 period, we cannot reject the hypothesis that supply chains are completely inflexible. In addition, we have shown the robustness of this finding to alternative price measures, including those that account for the U.S. dollar's outsized role in trade.

Strikingly, our results show that supply chains remain relatively inflexible even in the long run. In particular, while the longer horizon leads to larger elasticities overall, complementarities in production persist. In other words, expenditure decisions at the production stage remain less flexible to price changes than final-demand expenditure decisions even in the long-run.

The finding that global value chains are largely inflexible in the short-term and relatively inflexible in the long-run has important implications. From a business-cycle point of view, it underscores the importance of the international production structure in understanding how shocks to one country may reverberate around the world. While under flexible supply chains the value added by each country can be thought of as being directly exported to the country where it is finally consumed, the specifics of the international division of labor matter a great deal more under supply-chain inflexibility. In particular, temporary disruptions to a supply chain are much less easy to solve, as the chain itself is less flexible (as has been found, for example, in the case of natural disasters). This shows that the importance of supply chains found in studies focused on specific countries (as in e.g. Boehm et al., 2019, on the Japanese earthquake) is a more general phenomenon that is relevant across the world, as are recent increases in tariffs. At the same time, the relative insensitivity of producers to price changes also implies that economies that exhibit a lot of final consumption matter more in competitiveness calculations. In particular, it significantly raises the importance of exchange-rate changes vis-à-vis countries in other regions that consume final goods and reduces the importance of partners within the same regional value chain (Bayoumi et al., 2018).

Looking to the future, it would be interesting to examine the results excluding commodity trade. This would allow us to exclude “traditional” supply chains in which commodities are sent abroad to be incorporated into other goods, and focus more on the “new” supply chains based on incorporating manufacturing components and complementary services in global production chains.

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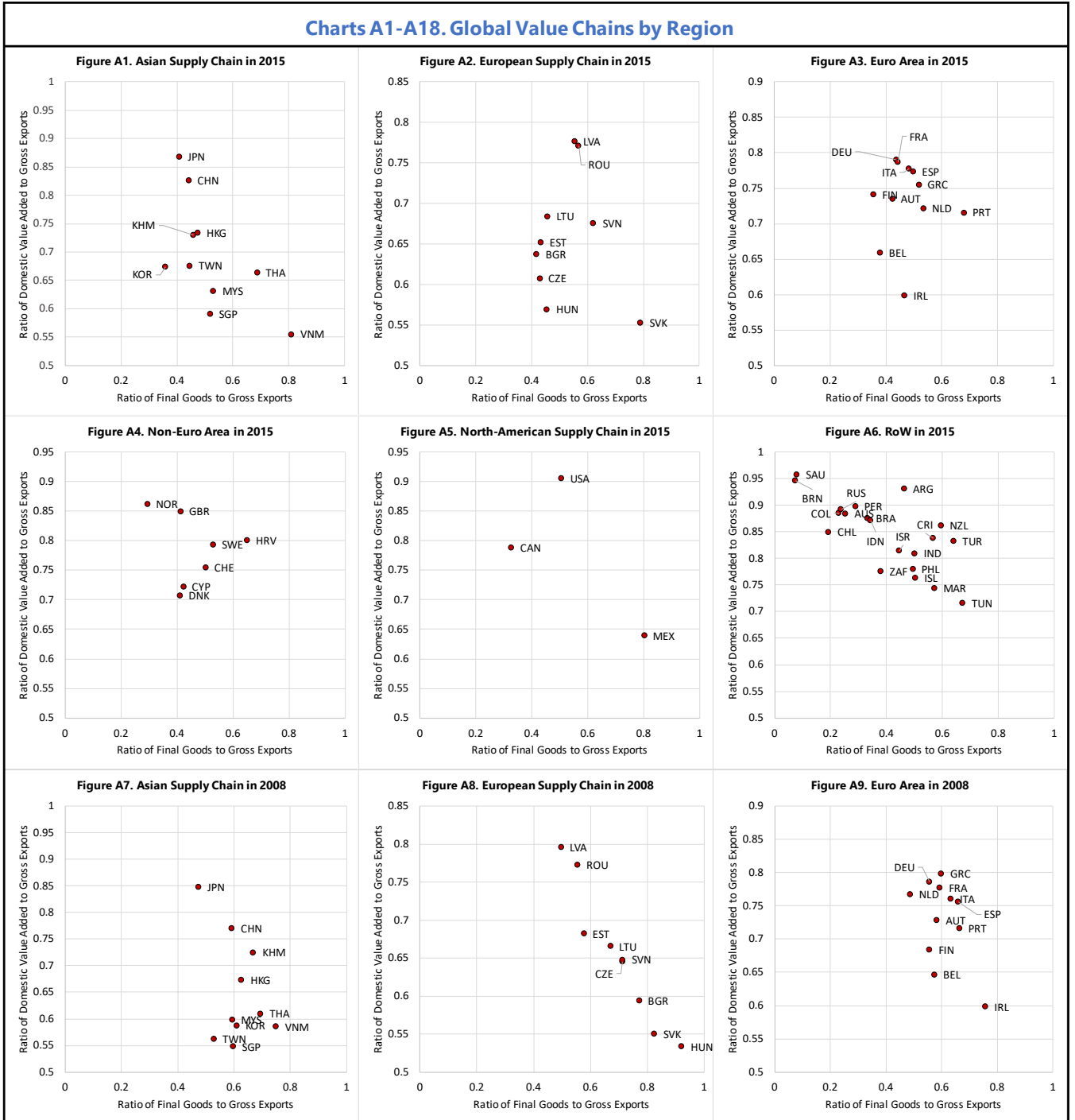
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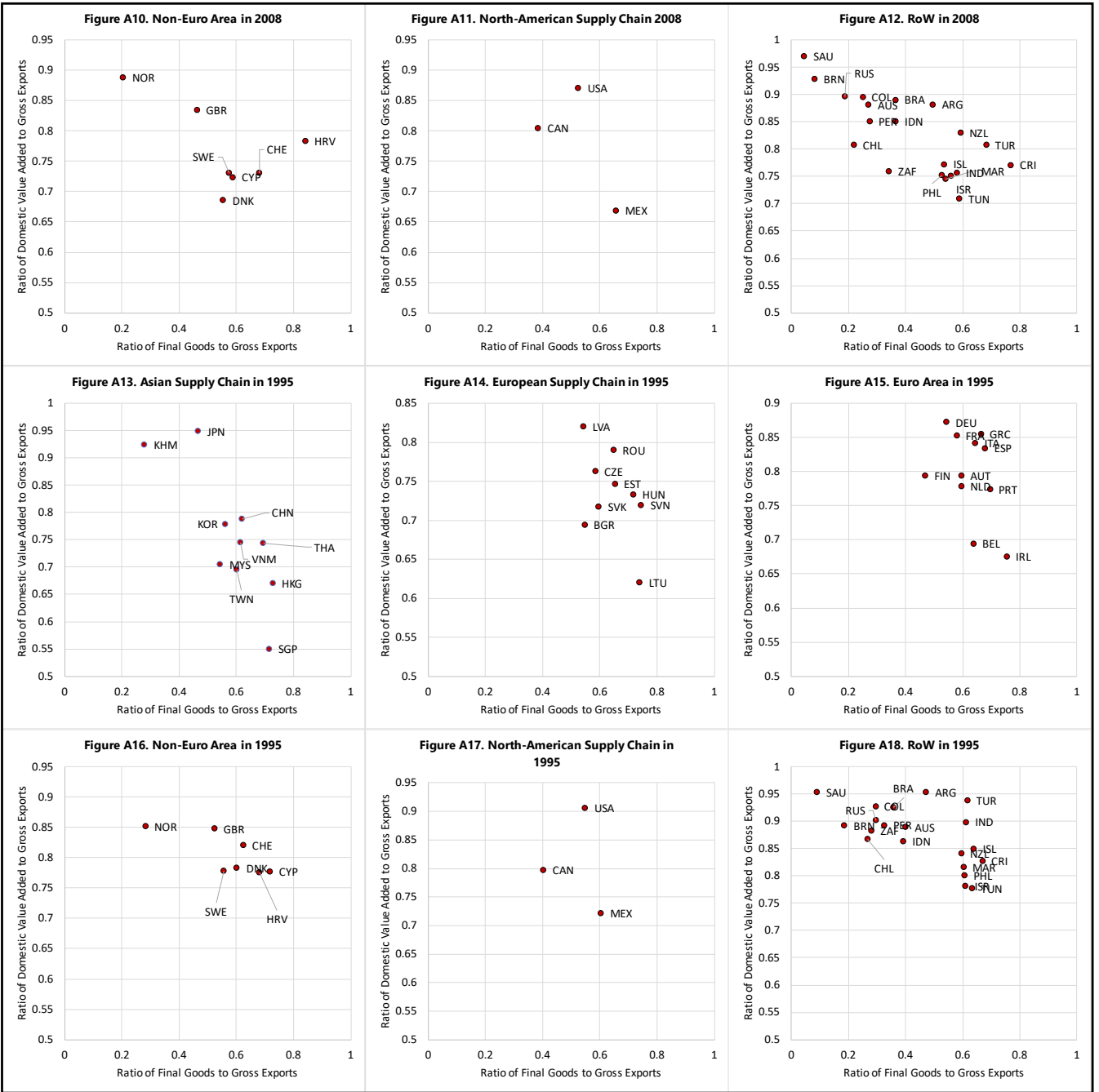
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VIII. APPENDIX A: ADDITIONAL CHARTS AND TABLES





IX. APPENDIX B: GAUGING THE DEGREE OF INFLEXIBILITY IN THE FULL SAMPLE

In order to gauge the precise extent to which supply chains are inflexible in the short run using the entire (1995-2015) sample, assume trade of final goods comprises two types of goods, one involving a fully flexible value chain (F) and the other a completely inflexible one (I). For the flexible case the relevant equation is $\widehat{FFVA} = \alpha REER^*$. For the inflexible one it is $\widehat{IFVA} = \alpha \left[\frac{IFVA}{I} \times REER^* + \frac{IDVA}{I} \times REER \right]$, where $I = IFVA + IDVA$. We can get the aggregate elasticity as

$$\begin{aligned}
 \widehat{FVA} &= \frac{FFVA}{FVA} \widehat{FFVA} + \frac{IFVA}{FVA} \widehat{IFVA} \\
 &= \frac{FFVA}{FVA} \alpha REER^* + \frac{IFVA}{FVA} \alpha \left[\frac{IFVA}{I} \times REER^* + \frac{IDVA}{I} \times REER \right] \\
 &= \alpha \left\{ \left(\frac{FFVA}{FVA} + \frac{IFVA}{FVA} \frac{IFVA}{I} \right) \times REER^* + \frac{IFVA}{FVA} \frac{IDVA}{I} \times REER \right\} \\
 &= \alpha \left\{ \left(1 - \frac{IFVA}{FVA} \frac{IDVA}{I} \right) \times REER^* + \frac{IFVA}{FVA} \frac{IDVA}{I} \times REER \right\} \quad (6)
 \end{aligned}$$

According to our estimates (cf. equation (5)), and disregarding in the notation the distinction between parameters and their estimates, expression (6) implies that

$$\alpha \left(1 - \frac{IFVA}{FVA} \frac{IDVA}{I} \right) = -\frac{2}{3}, \text{ and}$$

$$\alpha \frac{IFVA}{FVA} \frac{IDVA}{I} = -\frac{1}{2}.$$

Solving the two equations in the two unknowns yields $\alpha = -7/6$ and

$$\frac{IFVA}{FVA} \frac{IDVA}{I} = 3/7. \quad (7)$$

Equation (7) pins down the product of the share of foreign value added produced under Leontief supply chains and the share of domestic value added in such Leontief supply chains. We are mostly interested in the ratio $\frac{IFVA}{FVA}$, i.e. how much of foreign value added could be seen as part of fully-inflexible supply chains. To know that, we need to have an estimate of how much domestic value added contributes to inflexible supply chains, i.e. $\frac{IDVA}{I}$. Arguably, the domestic value added share over the total (flexible and inflexible) value added exports likely provides an upper bound for $\frac{IDVA}{I}$. The reason underlying this conjecture is that complex global supply chains (as e.g. those involved in building aircraft or other highly-specialized goods) likely have a higher foreign value added content than the ones involved in the production of less-specialized goods for which domestic suppliers may be able to provide many of the inputs. The 2015 cross-country average domestic value added share of exports in our dataset is 0.75.²¹ Thus, the foreign-value added coefficient estimates suggest that $\frac{IFVA}{FVA} \geq \frac{3/7}{0.75} \cong 0.6$. That is, in the short run global supply chains can be thought of as being at least 60 percent fully inflexible.

²¹ For example, Timmer et al. (2015, Table 1) show that, as of 2008, German value added represents only 66 percent of the total value of Germany's automotive output, a sector that is likely subject to a more specialized, and thus more rigid, production structure. This underscores our point about using 0.75 as an upper bound on the domestic value added share in inflexible supply chains.

Table A1. Export deflators (baseline) v. GDP deflators

	(1)	(2)	(3)	(4)
	FVA		DVA	
	Baseline (export deflator)	GDP deflator	Baseline (export deflator)	GDP deflator
LONG RUN				
Importing partners' EER	-2.252 (-5.45)***	0.205 (0.66)		
Own EER x DVA share	-0.607 (-4.60)***	-0.323 (-2.16)**		
Importing partners' EER	1.295 (5.07)***	0.556 (2.17)**		
Own EER			-0.750 (-6.34)***	3.976 (3.91)***
Importing partners' EER			-0.435 (-0.75)	0.861 (0.36)
Own EER x FVA share			1.381 (2.31)**	3.079 (1.29)
Foreign demand	0.170 (1.51)	-0.441 (-2.91)***	0.455 (3.80)***	5.722 (5.48)***
Oil price	0.156 (3.89)***	0.213 (4.57)***	-0.0728 (-2.31)**	-1.161 (-4.16)***
Non-fuel commodity	0.262 (4.28)***	0.152 (2.32)**	0.204 (6.08)***	-0.846 (-4.04)***
SHORT RUN				
Error-correction term	-0.202 (-7.10)***	-0.222 (-7.80)***	-0.155 (-6.49)***	-0.00682 (-0.92)
Importing partners' EER	-0.640 (-2.94)***	-0.456 (-1.77)*		
Own EER x DVA share	-0.477 (-4.43)***	-0.543 (-5.10)***		
Importing partners' EER	0.677 (5.56)***	0.651 (5.51)***		
Own EER			-0.297 (-1.54)	-0.287 (-1.92)*
Importing partners' EER			-0.719 (-1.01)	-1.156 (-1.47)
Own EER x FVA share			0.757 (1.05)	1.206 (1.50)
Foreign demand	3.227 (12.23)***	3.317 (15.16)***	2.174 (12.84)***	1.621 (8.44)***
Oil price	0.00901 (0.43)	0.0565 (2.71)***	-0.0769 (-5.55)***	-0.0236 (-1.91)*
Non-fuel commodity	0.124 (2.58)***	0.148 (3.17)***	-0.0105 (-0.29)	0.0572 (1.57)
Constant	1.899 (7.03)***	0.592 (6.74)***	0.741 (5.39)***	-0.267 (-0.97)
N	1,116	1,117	1,116	1,117

t statistics in parentheses

* p<0.1 ** p<0.05 *** p<0.01