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Measuring Openness

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Keywords

Measurement of Openness, Global Value Chains, Shock Propagation, Growth, Synchronization

JEL Classification

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1 Introduction

The evidence about the correlates of openness seems to depend on the data used. On the one hand, firm-level data unambiguously show that exporting firms tend to be more productive, more efficient, have higher growth, and pay higher wages than non-exporting firms.[1] On the other hand, global data collected either at country or at sector level do not display much correlation between economic performance and conventional measures of openness. At country level, Frankel and Romer (1999) document a positive correlation whereas Rodríguez and Rodrik (2000) and many others dispute the evidence. At sector level, the evidence is even more problematic: Figure 1 plots the conditional correlation between sector-level growth and openness as measured by the fraction of output that is exported directly, a standard measure. The correlation is negative and significant. We need a resolution of this contradiction. Perhaps there is no hope of finding confirmation of firm-level evidence because the correlation is not large enough to be visible in aggregated data, at sector or country level. Or perhaps the contradiction comes from inadequate measurement that is not grounded in theory. This paper takes the latter view, proposing a measure of openness that is theoretically sound.

We introduce a novel measure of the exposure to foreign shocks -openness- that computes the value of domestically produced goods sold to final consumers abroad. The measure, which we call HOT for "high order trade," is grounded in theory. In a multi-country, multi-sector model of intermediate trade, we demonstrate why HOT captures systematically the response of value added to foreign supply shocks. In the model it happens because value added and HOT respond proportionately to foreign supply shocks for plausible parameter values. This is not true of any other existing conventional measures of openness.

HOT presents two original features. First, it focuses on high order linkages through the value chain, unlike some standard measures like the percentage of production that is directly exported. Second, it proposes a decomposition of domestic output by location of final consumption. In that, it is different from existing characterizations of the value chain, that measure its length (see Antràs and Chor, 2018) or the fragmentation of trade (see Johnson and Noguera, 2012). Since it decomposes output rather than trade, the measure is meaningful even in sectors that trade very little directly across borders but can still be exposed to foreign shocks indirectly, most prominently services.

We test the theory in international sector-level data, where we show that HOT correlates positively with value added in levels and in growth rates. A bilateral version of HOT also correlates systematically with the extent of synchronization in cycles between sectors located in different countries. None of the usual measures of openness come close to any such result,

[1] See among many others the seminal studies of Bernard and Jensen (1995, 1999, 2004) in US data.

which presumably explains why the correlates of openness have never been successfully explored at sector level. We draw two conclusions. Firstly, the lack of evidence in aggregate or sector level data comes from inappropriate, ad-hoc measures of openness. Secondly, measuring a sector or a country's exposure to foreign shocks is best done using HOT, which is easy to construct from standard global datasets describing input-output linkages.[2] We believe this constitutes an helpful addition to the toolbox available to students of openness, especially at times of large shocks with global consequences.

In practice, HOT is easy to calculate from readily available input-output data. It is derived from the identity at the heart of input-output tables, equating gross output in a given sector to all of its downstream uses. We decompose the identity into the uses that are purely domestic and those that are not. In doing so, we allow for offshore outsourcing, in which segments of the supply chain are localized in different countries. This can happen more than once, so that several segments of the supply chain can be outsourced abroad. HOT takes high values close to one if most of the sector's gross output is in fact used across the border.[3]

Methodologically the downstream uses of a given good can be split into two infinite sums: One that isolates the purely domestic ones and one that contains all the others. The former summarizes all the ways in which the sector's output reaches final demand staying strictly within the same country. The latter includes all the ways borders are crossed down the supply chain: from domestic to foreign countries, onto other foreign countries, and potentially back home. This infinite sum reflects the "open" part of the supply chain, and is the main constituting element of HOT: It is equal to the difference between the Leontief inverse of the world input-output matrix and the Leontief inverse computed on the purely domestic component of the world input-output matrix. That is, it is given by the difference between all the uses for a given sector's output and all of its purely domestic uses.[4]

HOT is computed using the 2016 release of the World Input-Output Database (WIOD) for 50 sectors in 43 countries between 2000 and 2014, which represents about 85 percent of world GDP. HOT correlates highly with existing measures across countries, with small countries like Luxembourg or Ireland at the top of the distribution and large ones like Japan or the U.S. at the bottom. On average, the median value of HOT for services is above 0.40, much more open than for example Construction or Real Estate, both around 10 percent. Services are consistently

[2]In the terminology set out by Antràs and Chor (2021), our approach is "macro" by nature since we examine measures of openness across countries and sectors. The complementary "micro" approach based on firm-level information still presents some limitations, since "there remains significant hurdles to linking micro datasets across countries" for instance because of confidentiality or compatibility issues (Antràs and Chor, 2021, Section 2.2).

[3]Input-output tables are silent about firm boundaries, so that HOT can in fact correlate with the existence of multinational companies. See Fally and Hillberry (2018), Alfaro et al. (2019), or Atalay et al. (2019).

[4]Hummels, Ishii, and Yi (2001), Los, Timmer, and De Vries (2016) perform similar decompositions to isolate various components of trade. Bems, Johnson, and Yi (2010) use a similar measure to dissect the great trade collapse of 2008-2009. Bems and Johnson (2017) use it to introduce value added exchange rates.

more open according to HOT than according to alternatives. In fact, some services are among the most open sectors in some countries - e.g., IT in India.

We consider three alternative measures of openness that are used most frequently in the literature to measure openness at sector or country level. First, the total value of direct exports as a fraction of value added, which we label X, following Alcalá and Ciccone (2004). Second, Trade in Value Added (TiVA), which captures the integration of exports with the global value chain, as introduced by Johnson and Noguera (2012). And third, the so-called “phiness” of trade ϕ, which normalizes bilateral trade values as predicted by a gravity model to approximate trade costs, see Baldwin et al. (2003) or Head and Mayer (2004). Not many other measures of openness exist that have been used at sector or country level.[5]

According to these conventional measures, the distribution of openness across sectors is highly skewed: open sectors are the exception, even in open countries. For example, the median value of X in Denmark is below 10 percent, suggesting that most sectors are in fact relatively closed even in a small open economy. The same is true of TiVA. In contrast, the distribution of HOT across sectors is symmetric: Some sectors are open even in countries that are relatively closed on average, and most countries have a distribution of HOT that spans most of its support, between 0 and 1. This is intuitive: while many sectors do not trade directly across the border, most sectors trade indirectly across a border, including services.

These differences do not imply that HOT is necessarily a good measure of a sector’s exposure to foreign shocks. To address this important question we turn to theory and exploit a multi-sector, multi-country model of international trade adapted from Huo et al. (2021). We simulate the model country by country (except the US) and subject each sector in each country to a combination of two aggregate supply shocks: one that affects the simulated economy and the other that originates in the US, which constitutes the source of foreign shocks. We evaluate how the various measures of openness -HOT, TiVA, X, and ϕ- manage to replicate the simulated responses of value added to this combination of shocks. We use the resulting 50×42 = 2,100 simulated data points to evaluate in a regression setting which of the measures of openness is most correlated with the simulated response of value added. We find that HOT is the only measure that displays a robust significant positive correlation: All the others are insignificant or unstable. Unlike X and ϕ (but like TiVA), HOT is constructed on the basis of Leontief inverses of the world input-output matrix and as such keeps track of the full propagation of foreign shocks, see Acemoglu, Akcigit, and Kerr (2016). And unlike TiVA, HOT summarizes the contribution of foreign shocks to *output*. If openness is to be understood as exposure to foreign (supply) shocks, then HOT is the only theoretically sound measure of the response of

[5] Tariffs data are often used, but they are isomorphic to the phiness of trade. Waugh and Ravikumar (2016) introduce a measure based on the welfare gains of trade.

activity to openness.[6]

The shocks are well identified in the simulation but not in the data, where many are likely to occur simultaneously in many locations. The question is whether the superiority of HOT in the model continues to hold, on average, in the data. We explore this through three empirical tests that are common in country- and firm-level data (although typically available for very few countries). We first ask whether a sector openness correlates systematically with the level of production, a question many times asked in firm-level data.[7] Second we ask whether openness correlates with growth, a question that was first asked across countries and more recently at firm level.[8] Third and finally, we introduce a bilateral version of HOT and ask whether it correlates with the synchronization of business cycles at sector level.[9]. We document a systematic positive and significant correlation between HOT, production, growth, and synchronization at sector level. The estimates have the wrong sign and are unstable using conventional openness measures. These results confirm in the data what the model establishes in theory.

This is not the first paper proposing to incorporate input-output linkages in measures of openness. Tintelnot et al. (2018) introduce a measure similar to ours in Belgian firm-to-firm data to study how international trade affects wages and unit costs at firm level. A large literature uses Leontief inverses to isolate the value-added component of trade, TiVA. The main idea is to obtain a measure of trade that is commensurate with national accounts, i.e., expressed in terms of value created rather than gross output (see for instance Johnson and Noguera, 2012, Koopman et al., 2014, Bems and Kikkawa, 2021, or Bems and Johnson, 2017). Our objective is different: While this literature introduces a measure of trade that is consistent with national accounts, we introduce a measure of openness that is consistent with theoretical propagation channels.

It is hard to measure the openness of services. Data on service trade are available from balance of payments statistics, but a breakdown into constituent service sectors is very hard to come by. The Bureau of Economic Analysis proposes a decomposition into nine categories for U.S. service trade, but the breakdown is not particularly useful.[10] What we know is that service trade as a whole has risen since the 1980s, without much of a commensurate fall in formal

[6] X, TiVA and ϕ have their own purposes: X is direct trade, TiVA identifies the components of trade in the presence of value chains, and ϕ measures trade costs. Our point is that these should not be used to measure openness as defined by the exposure of economic activity to foreign shocks.

[7] See for example Bernard and Jensen (1995, 1999, 2004), Amiti and Konings (2007), Topalova and Khandelwal (2011), Bernard et al. (2018), or De Loecker and Van Biesebroeck (2018)

[8] See for instance the survey by Baldwin (2004) across countries, or Amiti and Konings (2007), Halpern et al. (2015) or Bøler et al. (2015) at firm level.

[9] That question is rampant in the aggregate (see Frankel and Rose, 1998 or Kalemli-Özcan et al., 2013) and at firm level -although for very few countries and in a firm-to-country rather than firm-to-firm setup. See for instance di Giovanni et al., 2017, 2018

[10] The categories are: Maintenance and repair services, Transport, Travel, Insurance Services, Financial Services, Charges for the use of intellectual property, Telecommunications, computers, and information services, Other business services, and Government goods and services.

protection. Unsurprisingly, a large literature has deployed treasures of ingenuity to decompose this increase into its sector components.[11] Our contribution is to introduce a precise measure of openness, directly applicable in services, and readily available from input-output data.

2 Measuring Openness

2.1 High Order Trade

By definition, the value of gross output in each sector must equal the value of all of its downstream final or intermediate uses. Formally, this can be written as

$$\mathrm{P}_i^r \, \mathrm{Y}_i^r = \sum_s \sum_j \mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs} + \sum_j \mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r, \tag{1}$$

where $\mathrm{P}_i^r \, \mathrm{Y}_i^r$ is the value of gross output in sector $r = 1, ..., \mathrm{R}$ of country $i = 1, ..., \mathrm{N}$, $\mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}$ is the value of intermediate uses of this good in country j and sector s, and $\mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r$ is the value of its final uses in country j. Throughout the paper, subscripts denote countries and superscripts denote sectors. Both indexes are ordered so that the first identifies the location of production, and the second identifies the location of use.

The identity can be decomposed according to border crossings:

$$\mathrm{P}_i^r \, \mathrm{Y}_i^r = \left[\sum_s \sum_{j \neq i} \mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs} + \sum_{j \neq i} \mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r \right] + \left[\sum_s \mathrm{P}_{ii}^{rs} \, \mathrm{M}_{ii}^{rs} + \mathrm{P}_{ii}^r \, \mathrm{C}_{ii}^r \right], \tag{2}$$

where the second term isolates a component focused on domestic uses only. Define $a_{ij}^{rs} = \frac{\mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}}{\mathrm{P}_j^s \, \mathrm{Y}_j^s}$ the dollar amount of output from sector r in country i needed to produce one dollar worth of output in sector s of country j, i.e., the entry in a direct requirement matrix. The identity becomes

$$\mathrm{P}_i^r \, \mathrm{Y}_i^r = \left[\sum_s \sum_{j \neq i} a_{ij}^{rs} \, \mathrm{P}_j^s \, \mathrm{Y}_j^s + \sum_{j \neq i} \mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r \right] + \left[\sum_s a_{ii}^{rs} \, \mathrm{P}_i^s \, \mathrm{Y}_i^s + \mathrm{P}_{ii}^r \, \mathrm{C}_{ii}^r \right]. \tag{3}$$

[11] One approach is to compute the phiness of service trade using intermediate trade as reported in input-output tables, see for instance Eaton and Kortum (2018). Another approach is to compute TiVA for services. For example, Johnson (2014) shows service trade is larger in value-added terms than in gross terms, reflecting the fact that service trade is mostly indirect across borders. Yet another approach is to infer international trade in services from local trade in services, see for instance Jensen and Kletzer (2005), Eckert et al. (2019), and Gervais and Jensen (2019). A final approach is to build from the fact that goods and services trade have similar determinants (distance, borders, gravity), so that service trade is related with goods trade. The focus is on services that support goods production, see for instance Eaton and Kortum (2018), Christen and François (2017), or Egger et al. (2017).

Iterating the identity,

$$
\begin{aligned}
\mathrm{P}_i^r\,\mathrm{Y}_i^r = & \Big[\mathrm{P}_{ii}^r\,\mathrm{C}_{ii}^r + \sum_s a_{ii}^{rs}\,\mathrm{P}_{ii}^s\,\mathrm{C}_{ii}^s + \sum_s\sum_t a_{ii}^{rs}a_{ii}^{st}\,\mathrm{P}_{ii}^t\,\mathrm{C}_{ii}^t + \dots\Big] \\
& + \Big[\sum_{j\neq i}\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r + \sum_s\sum_{j\neq i}\left(a_{ij}^{rs}\,\mathrm{P}_{jj}^s\,\mathrm{C}_{jj}^s + a_{ii}^{rs}\,\mathrm{P}_{ij}^s\,\mathrm{C}_{ij}^s\right) \\
& + \sum_t\sum_s\sum_{j\neq i}\left(a_{ij}^{rs}\sum_k a_{jk}^{st}\,\mathrm{P}_{kk}^t\,\mathrm{C}_{kk}^t + a_{ii}^{rs}a_{ij}^{st}\,\mathrm{P}_{jj}^t\,\mathrm{C}_{jj}^t + a_{ii}^{rs}a_{ii}^{st}\,\mathrm{P}_{ij}^t\,\mathrm{C}_{ij}^t\right) + \dots\Big] \\
& \equiv (\mathrm{P}_i^r\,\mathrm{Y}_i^r)_{\,\mathrm{DOM}} + (\mathrm{P}_i^r\,\mathrm{Y}_i^r)_{\,\mathrm{FOR}}
\end{aligned}
\tag{4}
$$

The first infinite sum in equation (4), denoted with $(\mathrm{P}_i^r\,\mathrm{Y}_i^r)_{\,\mathrm{DOM}}$ collects all the manners in which production in sector r reaches final demand while never crossing a border, at any order. The second infinite sum $(\mathrm{P}_i^r\,\mathrm{Y}_i^r)_{\,\mathrm{FOR}}$ captures all the ways in which good r in country i can cross borders to meet final demand, again at any order. This term incorporates sequences of border crossings that reflect the offshoring of segments of production, i.e., a global value chain. $(\mathrm{P}_i^r\,\mathrm{Y}_i^r)_{\,\mathrm{FOR}}$ is the main constituting element of HOT.

Definition 1. *Define* HOT_i^r *by*

$$
\mathrm{HOT}_i^r = \frac{(\mathrm{P}_i^r\,\mathrm{Y}_i^r)_{\,\mathrm{FOR}}}{\mathrm{P}_i^r\,\mathrm{Y}_i^r}. \tag{5}
$$

HOT_i^r measures the fraction of production in sector r of country i that is subjected to foreign shocks via its downstream uses.

Proposition 1. *High order trade* HOT_i^r *is the typical element of the following Hadamard division*

$$
\Big[(\mathbf{I}-\mathbf{A}^m)^{-1}\,\mathbf{PC} - (\mathbf{I}-\mathbf{A}^m_{\mathrm{DOM}})^{-1}\,\mathbf{PC}_{\mathrm{DOM}}\Big] \oslash \Big[(\mathbf{I}-\mathbf{A}^m)^{-1}\,\mathbf{PC}\Big],
$$

where $\mathbf{PC}$ *denotes the vector of all final demand,* $\mathbf{PC}_{\mathrm{DOM}}$ *denotes final demand arising from the domestic country,* $\mathbf{A}^m$ *is an* $\mathrm{NR}\times\mathrm{NR}$ *matrix with typical element* a_{ij}^{rs}*, and* $\mathbf{A}^m_{\mathrm{DOM}}$ *is the* $\mathrm{NR}\times\mathrm{NR}$ *block-diagonal matrix with typical element* a_{ii}^{rs}*.*

2.2 Conventional measures of openness

We now describe the derivation of three conventional measures of openness: X, ϕ, and TiVA. At country level, the value of exports (or imports) is often normalized by GDP. At sector level, exports can be either in final or in intermediate trade, which in our notation can be rewritten as

$$
\mathrm{X}_i^r = \frac{\sum_{j\neq i}\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r + \sum_{j\neq i}\sum_s \mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs}}{\mathrm{P}_i^r\,\mathrm{VA}_i^r},
$$

where the numerator sums the value of total exports from sector r in country i, in final goods with $\sum_{j\neq i} \mathrm{P}_{ij}^{r}\, \mathrm{C}_{ij}^{r}$ and in intermediate goods with $\sum_{j\neq i}\sum_{s} \mathrm{P}_{ij}^{rs}\, \mathrm{M}_{ij}^{rs}$. The denominator is nominal value added in the sector converted in USD at PPP exchange rates, following Alcalá and Ciccone (2004).[12]

An alternative is to normalize direct trade in a way that is guided by theory. Baldwin et al. (2003) and Head and Mayer (2004) introduce a measure inspired directly from the gravity model that they label the "phiness" of trade. The idea is to normalize direct bilateral trade at sector level by adequately chosen aggregates so that the ratio maps into trade costs in a way that is grounded in theory. They show that the cost of trading good r between country i and country j maps into

$$\phi_{ij}^{r} = \left(\frac{(\mathrm{P}_{ij}^{r}\, \mathrm{M}_{ij}^{r} + \mathrm{P}_{ij}^{r}\, \mathrm{C}_{ij}^{r}) \times (\mathrm{P}_{ji}^{r}\, \mathrm{M}_{ji}^{r} + \mathrm{P}_{ji}^{r}\, \mathrm{C}_{ji}^{r})}{(\mathrm{P}_{ii}^{r}\, \mathrm{M}_{ii}^{r} + \mathrm{P}_{ii}^{r}\, \mathrm{C}_{ii}^{r}) \times (\mathrm{P}_{jj}^{r}\, \mathrm{M}_{jj}^{r} + \mathrm{P}_{jj}^{r}\, \mathrm{C}_{jj}^{r})}\right)^{\frac{1}{2}},$$

where $\mathrm{P}_{ij}^{r}\, \mathrm{M}_{ij}^{r} = \sum_{s} \mathrm{P}_{ij}^{rs}\, \mathrm{M}_{ij}^{rs}$ is the total value of the intermediate sales of good r produced in country i across all sectors in country j. The denominator contains each country's "imports from itself", calculated as the value of all shipments from sector r to any sector s that remain in the producing country. The phiness of trade for sector r in country i can then be defined by an average of ϕ_{ij}^{r} across partner countries j:

$$\phi_{i}^{r} = \frac{1}{J}\sum_{j\neq i} \phi_{ij}^{r}.$$

Johnson and Noguera (2012) introduce a measure of high order trade based on direct exports, TiVA_{i}^{r}. The measure captures the value added content of exports of good r produced in country i. TiVA_{i}^{r} is defined as the typical element of the following product

$$\left(\frac{\mathbf{PVA}}{\mathbf{PY}}\right)(\mathbf{I} - \mathbf{A}^{m})^{-1}\,(\mathbf{PC} - \mathbf{PC}_{\mathrm{DOM}})\,\mathbf{1}, \tag{6}$$

where $\frac{\mathbf{PVA}}{\mathbf{PY}}$ is an $\mathrm{NR}\times\mathrm{NR}$ diagonal matrix with the ratio of nominal value added to gross output in sector r of country i on the diagonal, $\mathbf{PC} - \mathbf{PC}_{\mathrm{DOM}}$ is the $\mathrm{NR}\times\mathrm{N}$ matrix of final good exports, and $\mathbf{1}$ is a $\mathrm{N}\times 1$ vector of ones. Omitting the vector $\mathbf{1}$ implies the bilateral version of TiVA, TiVA_{ij}^{r}. By applying the Leontief inverse matrix to direct exports, TiVA measures the value added content of exports.

It is useful to review the differences between TiVA and HOT. TiVA measures the fragmentation of exports, their integration in the global value chain. Instead, HOT measures the fragmentation of output, the fraction of gross output that is sold across a border. This difference

[12]Using market exchange rates instead does not change any of our conclusions.

is apparent from the fact that HOT applies different Leontief inverses to $\mathbf{PC}$ and to $\mathbf{PC}_{\text{DOM}}$, whereas TiVA applies the same, i.e., decomposes exports. For the same reason HOT can be computed for sectors that do not directly trade abroad, since it decomposes output, whereas it is harder for TiVA. Second, HOT is naturally bounded between 0 and 1, whereas TiVA is not since it measures the nominal value added content of trade. As a result TiVA is often normalized. One option is to divide it by total exports to quantify the importance of indirect trade relative to observed direct exports. With this normalization, TiVA will take very high (infinite) values in non traded sectors. Another option is to normalize TiVA by value added instead, which accounts for scale. For example Duval et al. (2016) do so to investigate the impact of value added trade on the international synchronization of GDP.

Following the literature, we therefore define two variants of TiVA,

$$\mathrm{T}_i^r(\mathrm{X}) = \frac{\mathrm{TiVA}_i^r}{\sum_j \mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r + \sum_j \sum_s \mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}}, \quad \mathrm{T}_i^r(\mathrm{VA}) = \frac{\mathrm{TiVA}_i^r}{\mathrm{P}_i^r \, \mathrm{VA}_i^r},$$

In what follows, we compare HOT with the four alternatives just listed, X, ϕ, and the two versions of T.

2.3 Computing the measures

Define the world input-output matrix $\mathbf{W}$ with typical element $\mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}$. $\mathbf{W}$ contains the bulk of the information available from WIOD: It reports intermediate trade within and between countries, augmented with vectors of final demand $\mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r$. Final demand breaks down into a domestic and an international component by country j, but not by sector s. These are the key ingredients needed to compute HOT.

In addition, $\mathbf{W}$ also keeps track of the net inventories INV_{ij}^r in sector r of country i, broken down by country use j, but not by sector use s. To account for inventories, we follow Antràs and Chor (2013, 2018) and correct the input-output data in WIOD according to a proportion rule. We rescale each entry $\mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}$ and $\mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r$ in $\mathbf{W}$ by $\mathrm{P}_i^r \, \mathrm{Y}_i^r / (\mathrm{P}_i^r \, \mathrm{Y}_i^r - \mathrm{INV}_i^r)$ where $\mathrm{INV}_i^r = \sum_j \mathrm{INV}_{ij}^r$. We denote with $\mathbf{W}^*$ the resulting rescaled input-output matrix.

The direct requirement matrix $\mathbf{A}^m$ is then computed on the basis of this rescaled input-output matrix. The typical element of $\mathbf{A}^m$, a_{ij}^{rs}, is the typical element in $\mathbf{W}^*$ normalized by the column-wise sum of its elements, i.e. sector-level gross output (corrected for inventories). To define $\mathbf{A}_{\text{DOM}}^m$ we extract the block diagonal of $\mathbf{A}^m$ that contains the within country components of the direct requirement matrix. We also extract the domestic components of $\mathbf{PC}$ to define $\mathbf{PC}_{\text{DOM}}$.

The 2016 release of WIOD provides data for 43 developed and developing countries from 2000 to 2014. This represents approximately 85 percent of world GDP. The input-output data are in millions USD at current prices and are available for 56 sectors for each country and each year. We exclude 6 public sectors from our analysis.[13]

We use the information on yearly value added to compute the relevant measures of sector and aggregate value added, growth, and synchronization. These measures are deflated when necessary using the sector price indices from the socio-economic accounts available with the 2016 release of WIOD. Data on PPP exchange rates come from the OECD. Detail on the computation of all variables can be found in Appendix D.

2.4 Stylized facts

Table 1 reports the correlations between the five measures of openness we consider: HOT, X, ϕ, $\mathrm{T(X)}$, and $\mathrm{T(VA)}$. Several results are of interest. First, HOT, X, and $\mathrm{T(VA)}$ are positively correlated, suggesting the three measures tend to imply similar rankings across countries and sectors. Second $\mathrm{T(X)}$ captures something quite different from all other variables: Its correlation is essentially zero with all other measures. This reflects the fact that $\mathrm{T(X)}$ does not measure output's exposure to foreign shocks: It measures the integration of a sector's exports with the supply chain. ϕ also behaves quite differently from the other measures, with correlation coefficients that are mostly below 0.2.

Figure 2 reports the median values of HOT, ϕ, X, $\mathrm{T(X)}$, and $\mathrm{T(VA)}$ in each country, where all five panels are ranked according to HOT. The ranking of countries according to HOT is not surprising in the sense that small countries tend to have large median values, and large countries tend to have low median values. Consistent with Table 1, the country ranking according to X or $\mathrm{T(VA)}$ is by and large similar to HOT but it is quite different according to ϕ and $\mathrm{T(X)}$.

Figure 3 reports the median values of HOT, ϕ, X, $\mathrm{T(X)}$, and $\mathrm{T(VA)}$ in each sector, where all five panels are again ranked according to HOT. The ranking of sectors according to HOT resembles the ranking according to X, ϕ, and $\mathrm{T(VA)}$. However, the distribution of median values is very different for direct and indirect measures: HOT and $\mathrm{T(VA)}$ imply much higher openness at sector level for many more sectors than X and ϕ, whose distributions are skewed in the sense that most sectors tend to be closed.

Figure 4 plots country-level averages of HOT over time for five large economies, along with a world average. The country ranking is not surprising: Germany is the most open country of the five, followed by China, India, Japan, and the U.S. All countries display a short-lived dip in 2009, the great trade collapse that followed the great financial crisis. Openness at country level as implied by HOT is not dramatically different from what conventional measures imply; But as we now discuss, the differences are large at sector level.

[13]See http://www.wiod.org/database/iot.html and Dietzenbacher et al. (2013) for details on the methodology used to construct these data.

Figures 2, 3, and 4 are constructed on samples that omit a few sectors and countries for some measures. It is worth spending some time on these omissions. All variables except HOT have extremely skewed distributions, due to a few very high observations. For example in Germany in 2014, ϕ is in the millions, while X takes a value above 50. As seen on Figure 2 where these outliers are omitted, the values for other countries are orders of magnitude smaller. Across sectors, ϕ takes values in the hundreds of millions in Textiles and Machinery, and X is around 70 in Petrol, more than 30 times the next largest value across sectors (as seen on Figure 3). Obviously these are outliers, which are due to the normalizations inherent to measuring X and ϕ. Dealing with extreme values will be of the essence in regression analysis: It is probably a reason why conventional international data on openness at sector level perform so poorly empirically. We emphasize that HOT displays a well-behaved distribution with no apparent outliers, i.e., the figures showing values for HOT include all observations.

Figure 5 plots density estimates of HOT, X, ϕ, $\mathrm{T(X)}$, and $\mathrm{T(VA)}$. The contrast between HOT and the other measures is striking: HOT is much more symmetric than the four other measures, mildly skewed to the right with a mode around 0.2. The four other measures are highly skewed to the right, with most observations very close to zero. X, ϕ, $\mathrm{T(X)}$ and $\mathrm{T(VA)}$ also display very large upper tails presumably because of normalization issues. According to conventional measures, most sectors are closed and very few are open. According to HOT, most sectors are relatively open, very few are closed, and some are very open.

Figure 6 plots the boxplots (minimum, interquartile range, maximum) of HOT, X, ϕ and both normalizations of T across sectors for all countries. The countries are ordered according to the median value of HOT. The resulting ranking is not surprising: distributions in small economies tends to be centered on high values of HOT, like in Ireland, the Netherlands, Luxembourg, or Belgium. And distributions in large countries tends to be centered on low values of HOT, like in Brazil, the U.S., India, or Japan. The distributions cover a broad range in most countries. There are open sectors in relatively closed countries: for example, HOT takes maximum values above 0.6 in some sectors in Japan and around 0.4 in some sectors in the U.S. And there are closed sectors in open economies, even in Ireland or the Netherlands where minimum values for HOT are below 0.1.

The distributions look radically different for the four other measures, as shown in the lower panels of Figure 6. According to all other measures median openness is much lower; both open and closed countries have a majority of closed sectors. This is both true of measures based on direct trade (X, ϕ) and of measures based on indirect trade ($\mathrm{T(X)}$ and $\mathrm{T(VA)}$). According to conventional measures of openness most sectors are closed, but not according to HOT. Most sectors do not trade across the border directly, but most do trade across the border indirectly.

Figure 7 plots the boxplots for HOT, X, ϕ, $\mathrm{T(X)}$, and $\mathrm{T(VA)}$ across countries for all sectors. The sectors are ranked according to median values of HOT. Some results are unsurprising:

Manufacturing activities tend to display distributions of HOT centered around high values. Activities like Construction, Hotels, Real Estate, or Retail tend to be centered on relatively low values of HOT, below 0.2. However, even in these extreme cases the cross-country distributions of HOT are broad ranged. For instance in Retail, HOT ranges from close to 0 to above 0.5: Some services are very open in some countries.

The lower panels of Figure 7 reports the same distributions for the other measures and they are not nearly as dispersed as HOT. According to all other measures, most sectors tend to be closed, and they tend to be closed in all countries. The view that some sectors are closed in all countries prevails for services: for example Retail, Wholesale Trade or Wholesale Retail are closed everywhere according to X or ϕ. HOT paints a very different picture of "closed" sectors in general, and services in particular. According to HOT services are in fact rather open on average: median HOT in Wholesale trade, Business services like Legal, Accounting or Marketing services, Architecture, or Administrative services are all around or above 0.4, with top values around 1 in some countries. According to HOT, there are countries where services are very exposed to foreign shocks, just like there are countries where manufacturing is in fact relatively closed.

3 The model

This Section presents a multi-country, multi-sector model with input-output linkages adapted from Huo et al. (2021) and amenable to simulation. We first present the building blocks of the model. We model and simulate the responses to shocks of output and openness measured in a variety of ways. We examine the correlations between the simulated measures of openness and the simulated response of output.

3.1 Building blocks

Production in sector r of country i is given by

$$\mathrm{Y}_i^r = \mathrm{Z}_i^r \ \left[(\mathrm{H}_i^r)^{\alpha^r}(\mathrm{K}_i^r)^{1-\alpha^r}\right]^{\eta^r} (\mathrm{M}_i^r)^{1-\eta^r},$$

where Z_i^r is a supply shock, H_i^r denotes labor input, K_i^r is capital input, and intermediate input $\mathrm{M}_i^r = \left(\sum_j \sum_s (\mu_{ji}^{sr})^{\frac{1}{\epsilon}} (\mathrm{M}_{ji}^{sr})^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}}$, with ϵ the elasticity of substitution between varieties of the intermediate goods. Capital is predetermined throughout this paper.[14] Cost minimization

[14]Huo et al. (2021) include a discussion of capital accumulation: They show that 80 percent of the dynamic response to shocks occurs on impact. The result is important for their purpose of extracting shocks from the data; It is less important for our purpose as we are using the model to simulate empirical measures of openness.

implies

$$\mathrm{W}_i^r\,\mathrm{H}_i^r = \alpha^r\eta^r\,\mathrm{P}_i^r\,\mathrm{Y}_i^r,$$
$$\mathrm{P}_{ji}^{sr}\,\mathrm{M}_{ji}^{sr} = \xi_{ji}^{sr}(1-\eta^r)\,\mathrm{P}_i^r\,\mathrm{Y}_i^r,$$

where W_i^r denotes the wage in (i,r), P_{ji}^{sr} is the price of the intermediate input produced in sector s of country j and used in sector r of country i, and P_i^r is the price of output in sector r of country i. The expenditure share ξ_{ji}^{sr} is given by

$$\xi_{ji}^{sr} = \frac{\mu_{ji}^{sr}(\tau_{ji}^s\,\mathrm{P}_j^s)^{1-\epsilon}}{\sum_{k,l}\mu_{ki}^{lr}(\tau_{ki}^l\,\mathrm{P}_k^l)^{1-\epsilon}},$$

where τ_{ji}^s denotes transport cost for sector s between countries j and i. Cost minimization implies that $\xi_{ji}^{sr} = \frac{\mathrm{P}_{ji}^{sr}\,\mathrm{M}_{ji}^{sr}}{\mathrm{P}_i^r\,\mathrm{M}_i^r}$. Throughout transport costs are such that $\mathrm{P}_{ji}^{sr} = \mathrm{P}_{ji}^s = \tau_{ji}^s\,\mathrm{P}_j^s$.

Households choose consumption to maximize $\mathrm{U}\left(\mathrm{C}_i - \sum_r(\mathrm{H}_i^r)^{1+\frac{1}{\psi}}\right)$ subject to $\mathrm{P}_i^c\,\mathrm{C}_i = \sum_r \mathrm{W}_i^r\,\mathrm{H}_i^r + \sum_r \mathrm{R}_i^r\,\mathrm{K}_i^r$, where

$$\mathrm{C}_i = \left[\sum_j\sum_s(\nu_{ji}^s)^{\frac{1}{\rho}}(\mathrm{C}_{ji}^s)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}},$$
$$\mathrm{P}_i = \left[\sum_j\sum_s(\nu_{ji}^s)(\mathrm{P}_{ji}^s)^{1-\rho}\right]^{\frac{1}{1-\rho}},$$

P_i^c is the consumption price index, ρ is the elasticity of substitution between final goods, and R_i^r denotes the rental rate of capital. Optimal labor supply is given by

$$\mathrm{H}_i^r = \left(\frac{\mathrm{W}_i^r}{\mathrm{P}_i^c}\right)^{\psi}.$$

Optimal expenditure shares in the final good are given by

$$\pi_{ji}^s = \frac{\nu_{ji}^s(\tau_{ji}^s\,\mathrm{P}_j^s)^{1-\rho}}{\sum_{k,l}\nu_{ki}^l(\tau_{ki}^l\,\mathrm{P}_k^l)^{1-\rho}} = \frac{\mathrm{P}_{ji}^s\,\mathrm{C}_{ji}^s}{\sum_{k,l}\mathrm{P}_{ki}^l\,\mathrm{C}_{ki}^l} = \frac{\mathrm{P}_{ji}^s\,\mathrm{C}_{ji}^s}{\mathrm{P}_i^c\,\mathrm{C}_i}.$$

We can now rewrite the resource constraint in equation (1) in the context of the model:

$$\mathrm{P}_i^r\,\mathrm{Y}_i^r = \sum_j \mathrm{P}_j^c\,\mathrm{C}_j\,\pi_{ij}^r + \sum_j\sum_s(1-\eta^s)\,\mathrm{P}_j^s\,\mathrm{Y}_j^s\,\xi_{ij}^{rs},$$

where we used the facts that $\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r = \mathrm{P}_j^c\,\mathrm{C}_j\,\pi_{ij}^r$ and $\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs} = (1-\eta^s)\,\mathrm{P}_j^s\,\mathrm{Y}_j^s\,\xi_{ij}^{rs}$. Following Huo et al. (2021) we impose financial autarky, which implies all of value added is consumed, i.e., $\mathrm{P}^c_j\,\mathrm{C}_j = \sum_s \eta^s\,\mathrm{P}^s_j\,\mathrm{Y}^s_j$. Market clearing becomes

$$\mathrm{P}^r_i\,\mathrm{Y}^r_i = \sum_j \sum_s \eta^s\,\mathrm{P}^s_j\,\mathrm{Y}^s_j\,\pi^r_{ij} + \sum_j \sum_s (1-\eta^s)\,\mathrm{P}^s_j\,\mathrm{Y}^s_j\,\xi^{rs}_{ij}. \tag{7}$$

In deviations for the steady state, the market clearing condition in equation (7) yields an expression for prices P^r_i in terms of quantities Y^r_i. The linearized production function in which optimal labor supply and material use are substituted yields an expression for quantities Y^r_i in terms of prices P^r_i. A closed form solution ensues for the equilibrium deviations of real sector output Y^r_i from the steady state. Huo et al. (2021) show that in deviations from the steady state the equilibrium response of output is given by

$$\ln \mathbf{Y}_t = \boldsymbol{\Lambda}^{-1} \ln \mathbf{Z}_t. \tag{8}$$

$\ln$ denotes deviations from the steady state and $\boldsymbol{\Lambda}$ is defined in Appendix A, where we also review the key steps of the derivation. Real gross output in sector (i, r) depends on the realization of shocks in all the sectors, domestic or foreign. Huo et al. (2021) label $\boldsymbol{\Lambda}^{-1}$ an "influence matrix" that summarizes the interdependence between sectors across countries via trade in intermediate and final goods.[15] $\boldsymbol{\Lambda}^{-1}$ takes the form of a Leontief inverse, so that shocks can affect output at any order. The property extends to the response of real value added, which by definition is given by

$$\ln \mathbf{V}_t = \frac{1}{\eta} \ln \mathbf{Z}_t + \alpha \ln \mathbf{H}_t, \tag{9}$$

With equilibrium labor, the response of value added becomes

$$\ln \mathbf{V}_t = \frac{1}{\eta} \ln \mathbf{Z}_t + \frac{\alpha\psi}{1+\psi}\Big[\ln \mathbf{PY}_t - \ln \mathbf{P}^c_t\Big].$$

It is useful to compare the equilibrium responses of real value added and HOT. By definition, the steady state value of HOT is given by

$$\begin{aligned}\mathrm{HOT}^r_i &= 1 - \frac{\mathrm{PY}^r_{i\,\mathrm{DOM}}}{\mathrm{PY}^r_i} \\ &= 1 - \frac{\sum_s \lambda^{rs}_{ii} bc^r_{ii}}{\sum_j \sum_s \lambda^{rs}_{ij} bc^r_{ij}},\end{aligned}$$

where λ^{rs}_{ij} is the typical element of $(\mathbf{I} - \mathbf{A}^m)^{-1}$. In deviations from the steady state,

$$\ln \mathbf{HOT}_t = \mathbf{H_1} \odot \Big(\ln \mathbf{PY}_t - \ln \mathbf{PY}_{\mathrm{DOM},t}\Big),$$

where $\frac{1-\mathrm{HOT}^r_i}{\mathrm{HOT}^r_i}$ is a typical element of $\mathbf{H_1}$ and $\odot$ is the Hadamard product. $\ln \mathbf{HOT}_t$ is pro-

[15]The influence matrix was introduced by Baqaee and Farhi (2019) in a long run model of international trade.

portional to the response of nominal output to foreign shocks, given by $\ln \mathbf{PY}_t - \ln \mathbf{PY}_{\text{DOM},t}$.

From its definition, we also know that the response of real value added to foreign shocks is given by

$$\ln \mathbf{V}_t - \ln \mathbf{V}_{\text{DOM},t} = \frac{\alpha\psi}{1+\psi}\left[\ln \mathbf{PY}_t - \ln \mathbf{PY}_{\text{DOM},t} - (\ln \mathbf{P}^c_t - \ln \mathbf{P}^c_{\text{DOM},t})\right],$$

where the domestic shocks $\ln \mathbf{Z}_t$ cancel out because they enter both expressions and $\ln \mathbf{P}^c_{\text{DOM},t}$ denotes the response of the consumer price index to domestic supply shocks. The responses of HOT and real value added are close to proportional for high substitutability in final and intermediate consumption, since then the responses of prices to supply shocks are muted. They become increasingly different as the elasticities fall. We expect therefore that HOT correlates most strongly with value added for $\rho, \epsilon > 1$. The correlation should be weaker for low substitutability. In addition, with high values of the elasticities positive supply shocks affect downstream demand positively since the increase in quantities is larger than the fall in prices. As a result downstream demand increases in response to upstream supply shocks with consequences throughout the network, which generalizes Acemoglu, Akcigit, and Kerr (2016).[16]

3.2 Simulations

We exploit the model to simulate the responses to supply shocks of all variables of interest. Our objective is to gauge which measure(s) of openness best replicate the simulated responses of real value added to a combination of domestic and foreign supply shocks. The responses of HOT ($\ln \mathbf{HOT}_t$) and of value added ($\ln \mathbf{V}_t$) are simulated using the equations obtained in Section 3.1. We now turn to the model-implied responses of the different measures of openness we have considered in Section 2. We do not include T(X) in the analysis given its low correlation with other measures.

Consider first total gross exports as a fraction of value added. In terms of the model, at the steady state we have:

$$\begin{aligned}
\text{X}^r_i &= \sum_{j\neq i} \frac{ac^r_{ij}\,\text{P}^c_j\,\text{C}_j}{\eta^r\,\text{P}^r_i\,\text{Y}^r_i} + \sum_s \sum_{j\neq i} \frac{\text{P}^{rs}_{ij}\,\text{M}^{rs}_{ij}}{\eta^r\,\text{P}^r_i\,\text{Y}^r_i} \\
&= \sum_{j\neq i} \frac{bc^r_{ij}}{\eta^r} + \sum_s \sum_{j\neq i} \frac{b^{rs}_{ij}}{\eta^r},
\end{aligned}$$

[16]See also Guerrieri et al. (2021).

In deviations from the steady state, this implies

$$\begin{aligned}\ln \mathrm{X}^r_{i,t} &= \frac{1}{\mathrm{X}^r_i}\Bigg[\sum_{j\neq i}\frac{ac^r_{ij}\,\mathrm{P}^c_j\,\mathrm{C}_j}{\eta^r\,\mathrm{P}^r_i\,\mathrm{Y}^r_i}(\ln \mathrm{P}^r_{ij,t}\,\mathrm{C}^r_{ij,t} - \ln \mathrm{P}^r_{i,t}\,\mathrm{Y}^r_{i,t})\\
&\quad + \sum_s\sum_{j\neq i}\frac{\mathrm{P}^{rs}_{ij}\,\mathrm{M}^{rs}_{ij}}{\eta^r\,\mathrm{P}^r_i\,\mathrm{Y}^r_i}(\ln \mathrm{P}^{rs}_{ij,t}\,\mathrm{M}^{rs}_{ij,t} - \ln \mathrm{P}^r_{i,t}\,\mathrm{Y}^r_{i,t})\Bigg]\\
&= \frac{1}{\eta^r}\frac{\sum_{j\neq i} bc^r_{ij}}{\mathrm{X}^r_i}\ln \mathrm{P}^r_{ij,t}\,\mathrm{C}^r_{ij,t} + \frac{1}{\eta^r}\frac{\sum_s\sum_{j\neq i} b^{rs}_{ij}}{\mathrm{X}^r_i}\ln \mathrm{P}^{rs}_{ij,t}\,\mathrm{M}^{rs}_{ij,t} - \ln \mathrm{P}^r_{i,t}\,\mathrm{Y}^r_{i,t}\,.\end{aligned}$$

In Appendix B we derive expressions for $\ln \mathrm{P}^r_{ij,t}\,\mathrm{C}^r_{ij,t}$, $\ln \mathrm{P}^{rs}_{ij,t}\,\mathrm{M}^{rs}_{ij,t}$, and $\ln \mathrm{P}^r_{i,t}\,\mathrm{Y}^r_{i,t}$ to substitute them into the definition of gross exports and obtain a reduced form expression for the response of gross exports to shocks.

The phiness of trade is given by a series of ratios of bilateral intermediate and final goods trade. At the steady state we have

$$\begin{aligned}\phi^r_{ij} &= \left(\frac{\Phi^r_{ij}}{\Phi^r_{ii}}\times\frac{\Phi^r_{ji}}{\Phi^r_{jj}}\right)^{\frac{1}{2}}\\
&= \left(\frac{\sum_s b^{rs}_{ij} + bc^r_{ij}}{\sum_s b^{rs}_{ii} + bc^r_{ii}}\times\frac{\sum_s b^{rs}_{ji} + bc^r_{ji}}{\sum_s b^{rs}_{jj} + bc^r_{jj}}\right)^{\frac{1}{2}},\end{aligned}$$

where $\Phi^r_{ij} = \sum_s \frac{\mathrm{P}^{rs}_{ij}\,\mathrm{M}^{rs}_{ij}}{\mathrm{P}^r_i\,\mathrm{Y}^r_i} + \frac{\mathrm{P}^r_{ij}\,\mathrm{C}^r_{ij}}{\mathrm{P}^r_i\,\mathrm{Y}^r_i}$ and we have normalized each term in the ratio by nominal output. In deviations from the steady state

$$\ln \phi^r_{ij,t} = \frac{1}{2}(\phi^r_{ij})^{-\frac{1}{2}}\Bigg(\ln \Phi^r_{ij,t} - \ln \Phi^r_{ii,t} + \ln \Phi^r_{ji,t} - \ln \Phi^r_{jj,t}\Bigg).$$

Aggregating to the country level

$$\begin{aligned}\ln \phi^r_{i,t} &= \sum_{j\neq i}\frac{\phi^r_{ij}}{\phi^r_i}\ln \phi^r_{ij,t}\\
&= \frac{1}{2}\sum_{j\neq i}\frac{(\phi^r_{ij})^{\frac{1}{2}}}{\phi^r_i}\Bigg(\ln \Phi^r_{ij,t} - \ln \Phi^r_{ii,t} + \ln \Phi^r_{ji,t} - \ln \Phi^r_{jj,t}\Bigg)\end{aligned}$$

Each element $\Phi^r_{ij,t}$ of $\ln \phi^r_{i,t}$ depends on $\ln \mathrm{P}^{rs}_{ij,t}\,\mathrm{M}^{rs}_{ij,t}$, $\ln \mathrm{P}^r_{ij,t}\,\mathrm{C}^r_{ij,t}$, and $\ln \mathrm{P}^r_{i,t}\,\mathrm{Y}^r_{i,t}$ whose expressions are derived in Appendix B. We use these expressions to spell out the corresponding reduced form expression for $\ln \phi^r_{i,t}$ in terms of the fundamentals of the model.

Trade in value added encapsulates high order linkages via the Leontief inverse $(\mathbf{I} - \mathbf{A}^m)^{-1}$

with typical element λ_{ij}^{rs}. At the steady state $\mathrm{T}_i^r(\mathrm{VA})$ is given by

$$\mathrm{T}_i^r(\mathrm{VA}) = \frac{\mathrm{TiVA}_i^r}{\mathrm{PVA}_i^r} = \sum_j \sum_s \lambda_{ij}^{rs} \frac{\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r - \mathrm{P}_{ii}^r\,\mathrm{C}_{ii}^r}{\mathrm{P}_i^r\,\mathrm{Y}_i^r}$$
$$= \sum_j \sum_s \lambda_{ij}^{rs}(bc_{ij}^r - bc_{ii}^r),$$

so that in deviations from the steady state

$$\ln \mathrm{T}_{i,t}^r(\mathrm{VA}) = \frac{\sum_j \sum_s \lambda_{ij}^{rs}}{\sum_j \sum_s \lambda_{ij}^{rs}(bc_{ij}^r - bc_{ii}^r)}(bc_{ij}^r \ln \mathrm{P}_{ij,t}^r\,\mathrm{C}_{ij,t}^r - bc_{ii}^r \ln \mathrm{P}_{ii,t}^r\,\mathrm{C}_{ii,t}^r) - \ln \mathrm{P}_{i,t}^r\,\mathrm{Y}_{i,t}^r\,.$$

$\ln \mathrm{T}_{i,t}^r(\mathrm{VA})$ depends on $\ln \mathrm{P}_{ij,t}^r\,\mathrm{C}_{ij,t}^r$ and $\ln \mathrm{P}_{i,t}^r\,\mathrm{Y}_{i,t}^r$, whose expressions are derived in Appendix B.

We simulate the responses of value added, HOT, X, ϕ, and $\mathrm{T}(\mathrm{VA})$ to a combination of domestic and foreign supply shocks. The simulations are performed country by country. Each country (except the US) is subjected to two shocks: a domestic aggregate supply shock and a US aggregate supply shock. All shocks are calibrated to the empirical standard deviation of aggregate gross output. We collect the sector-level responses of value added, HOT, X, ϕ, and $\mathrm{T}(\mathrm{VA})$ for all 42 countries, which implies a simulated dataset of 50 $\times$ 42 observations on which we perform regression analysis. We present the results in Tables 2 and 3.

Table 2 presents the simulated regression results, first between value added and HOT and then including the three other simulated openness measures as controls. The regressions are performed for different values of the elasticities ρ and ϵ. Theoretically we expect HOT to best capture the response of output to supply shocks for high substitutability in intermediate and final goods.[17] The simulation results are clear from Table 2: The responses of value added and HOT correlate positively and significantly for almost all parameter combinations. Including controls for X, ϕ, or $\mathrm{T}(\mathrm{VA})$ does not alter the result. In fact the coefficients on the alternative measures of openness are unstable and often negative and significant. The point estimates are larger when at least one of the two elasticities ρ or ϵ is greater than one; They are an order of magnitude smaller (but still positive and significant) when both elasticities are below one.

Table 3 completes the evidence by reporting the correlation between simulated value added and each of the three conventional measures of openness taken one at a time. It shows that in the model none of the three alternatives to HOT -X, ϕ, or $\mathrm{T}(\mathrm{VA})$- displays a systematic positive and significant correlation with value added. If anything most coefficients are negative and significant. HOT is the only variable that captures well the exposure of production to foreign supply shocks. That happens because HOT reflects the effect of foreign shocks on output (and

[17]The parametrizations of the elasticities are chosen on the basis of the estimates proposed in Huo et al. (2021). Appendix C presents further simulated regressions where we also let ψ vary.

not exports like X or $\mathrm{T(VA)}$) and it measures the effect of shocks at any order (and not their direct consequences only like X or ϕ).

4 Estimations

The simulations in Section 3.2 demonstrate that HOT performs best among openness measures at replicating the consequences of foreign supply shocks on output. We now examine whether this is also true empirically. Of course, in the data shocks happen everywhere and all the time so that we can only investigate which measure captures best their effects on average. We do so using the empirical counterparts of the model-implied steady state values of all four measures, discussed in Section 2. We consider three well-known correlates of openness: output, growth, and synchronization. We examine these correlations in an international sector-level database with coverage that we believe is unprecedented.

4.1 Openness and Value Added

We estimate a specification akin to Alcalá and Ciccone (2004), but perform the estimation in a panel of sectors across countries and over time, whereas Alcalá and Ciccone (2004) worked on a cross section of countries. Panel tests reject the null of non-stationarity in the cross section, but we also consider a specification in first differences.[18] We estimate:

$$\ln \mathrm{V}^r_{i,t} = \alpha_{ir} + \gamma_t + \beta_1 \, \mathrm{HOT}^r_{i,t} + \beta_2 \, \mathrm{X}^r_{i,t} + \beta_3 \, \phi^r_{i,t} + \beta_4 \; \mathrm{T}^r_{i,t}(\mathrm{VA}) + \varepsilon^r_{i,t}.$$

The specification allows for a time trend and for country-sector effects to absorb all the country-specific and sector-specific variation. For instance, these intercepts account for differences in country size, institutional quality, or capital intensity. Following the discussion in section 2.4, we winsorized the top 10 percent of observations for X and ϕ. We chose not to winsorize HOT or $\mathrm{T(VA)}$ reasoning their distributions do not suggest the presence of extreme values. We verified that winsorizing HOT and $\mathrm{T(VA)}$ does not alter substantially our results.

We also perform a decomposition of HOT into first vs. higher trade order to assess their separate importance. We define $\mathrm{HOT}^r_{i\ \text{order}=1} = \frac{\sum_{j \neq i} \mathrm{P}^r_{ij}\, \mathrm{C}^r_{ij}}{\mathrm{P}^r_i\, \mathrm{Y}^r_i}$, the value of direct final exports as a share of nominal output. $\mathrm{HOT}^r_{i\ \text{order}>1}$ summarizes all trade orders higher than one. Table 4 presents the results. HOT correlates significantly and positively with value added at sector level. The decomposition into $\mathrm{HOT}^r_{i\ \text{order}=1}$ and $\mathrm{HOT}^r_{i\ \text{order}>1}$ indicates that both components are relevant statistically, but the point estimate is two to three times larger on high orders. HOT remains positive and significant whether the other measures are included or not. In fact, HOT

[18] We implemented four types of panel unit-root tests: Fisher (also known as Phillips-Perron), Harris-Tzavalis, Breitung, and Levin-Lin-Chu tests, with one lag, demeaned series, and time trends. Unit roots were rejected in all cases.

is the only systematic correlate of value added: the coefficient estimates on X, ϕ, and $\mathrm{T(VA)}$ are unstable or have the wrong sign.

When we classify the 50 sectors in WIOD into three broad categories, Agriculture, Manufacturing, and Services, HOT correlates with value added in all three, albeit most weakly in Agriculture. On the other hand, value added does not correlate at all (or with the wrong sign) with the three other measures. Interestingly, HOT is the only measure of openness that correlates significantly with value added in Services, probably because it is the one that captures best their exposure to foreign shocks. The lower panel of Table 4 confirms these results in a first-differenced version of the specification.

4.2 Openness and Growth

The existence of a relation between openness and growth is a venerable research question. It is well established at firm level wherever these data are available, but elusive or unstable in aggregate data, sector or country.[19] Asking the growth question in a panel of sectors across countries is even more difficult as documented in Figure 1. We follow the approach in Rodrik (2013), extended to include services. Sector-level per capita value added growth is regressed on the initial level of value added per capita, measures of openness, and a battery of fixed effects. The data are winsorized as described in the previous section. We estimate

$$\Delta \ln \mathrm{V}^r_{i,\varsigma} = \alpha_r + \alpha_i + \beta_0 \ \ln \mathrm{V}^r_{i,\varsigma} + \beta_1 \, \mathrm{HOT}^r_{i,\varsigma} + \beta_2 \, \mathrm{X}^r_{i,\varsigma} + \beta_3 \ \phi^r_{i,\varsigma} + \beta_4 \ \mathrm{T}^r_{i,\varsigma}(\mathrm{VA}) + \varepsilon^r_{i,\varsigma}, \tag{10}$$

where ς denotes the period over which growth rates are computed and $\mathrm{V}^r_{i,\varsigma}$ is value added at the beginning of period ς.

Table 5 presents the results for all sectors in the first two specifications, and then for three broad categories of sectors in specifications (3), (4), and (5). There is conditional convergence as $\beta_0 < 0$ everywhere; Interestingly convergence holds in services. HOT correlates positively and significantly with growth, whether the other measures are included or not. As in the previous section, both $\mathrm{HOT}^r_{i\ \mathrm{order}=1}$ and $\mathrm{HOT}^r_{i\ \mathrm{order}>1}$ enter significantly but the point estimate is twice larger for high orders. The correlation is positive and significant in manufacturing sectors. In contrast, X, ϕ, and $\mathrm{T(VA)}$ display no stable significant correlation with growth, either in the aggregate or across all three broad sector categories.

The lower panel presents estimates of equation (10) using instrumental variables to address the possibility that openness and growth be co-determined. For example, positive shocks to final demand abroad mechanically increase HOT and they can also directly increase measured

[19] See for example the debates between Frankel and Romer (1999) and Rodríguez and Rodrik (2000)

value added growth. We introduce an instrument for the cross-section of HOT that makes use of its network properties. We have

$$\text{HOT}_i^r = 1 - \frac{\sum_s \lambda_{ii}^{rs}\,\text{PC}_{ii}^s}{\sum_s \sum_j \lambda_{ij}^{rs}\,\text{PC}_{ij}^s}.$$

By definition, the scalars λ_{ij}^{rs} are invariant to shocks. But final demand PC_{ij}^s is not, and shocks to final demand can also affect growth. We introduce an "adjacency vector" for final demand with element $\widetilde{\text{PC}}_{ij}^s = 1$ if $\text{PC}_{ij}^s \neq 0$, by analogy with an adjacency matrix where all non zero entries are set to unity. The vector captures *whether* final demand is strictly positive, a cross-section that barely changes over time.[20] The resulting instrument for HOT is defined as

$$\text{IVHOT}_i^r = 1 - \frac{\sum_s \lambda_{ii}^{rs}\widetilde{\text{PC}}_{ii,0}^s}{\sum_s \sum_j \lambda_{ij}^{rs}\widetilde{\text{PC}}_{ij,0}^s},$$

where $\widetilde{\text{PC}}_{ij,0}^s$ denotes final demand for good i, s arising from country j in year 0 (in practice the year 2000) and all non zero entries in $\text{PC}_{ij,0}^s$ are replaced with 1.[21]

The lower panel of Table 5 presents instrumental variable estimates using IVHOT. Whenever the coefficient is significant, the Anderson-Rubin tests suggest the instruments are not weak: There is no observable significant difference between the conventional confidence intervals and those implied by Anderson-Rubin, which are robust to weak instruments. At the aggregate level the coefficient on HOT increases sizably when it is instrumented, suggesting measurement error in the OLS estimation. This appears to happen because of services, for which estimates of β_1 become positive and significant with instruments, whereas they are zero in OLS.

4.3 Openness and Synchronization

Bilateral trade is well known to correlate with cycle synchronization. The evidence is well established between countries (see Frankel and Rose, 1998 or Kalemli-Özcan et al., 2013). In firm-level data we know that firms that are open to a particular country are synchronized with the cycle there (see di Giovanni et al., 2017, 2018). di Giovanni and Levchenko (2010) show that the international synchronization between sectors increases with direct intermediate trade, but they measure intermediate trade in the U.S. only and they are in cross-section.[22]

We now discuss our measurement strategy to extend the estimations in sections 4.1 and

[20] The correlation between "adjacency vectors" measured in 2000 and 2014 is 0.985.
[21] This instrumentation is only possible in a cross-section.
[22] Huo et al. (2021) and Huo et al. (2020) estimate TFP shocks at sector level purged from factor utilization and propagation via input-output linkages. Their purpose is to assess the role of sector-level TFP shocks for aggregate co-movements.

4.2 to a bilateral context. In theory the response of value added to foreign shocks is (close to) proportional to HOT. So the contribution of foreign shocks to co-movements should be closely related to a bilateral version of HOT given by

$$\mathrm{HOT}_{ij}^{rs} = \mathrm{HOT}_{i}^{r} \times \mathrm{HOT}_{j}^{s}.$$

By definition HOT_{ij}^{rs} reflects how much two sectors are open to each other and how much they are each open to foreign shocks happening in third countries, at any order through the supply chain. The measure conflates bilateral and multilateral sources of co-movements.

We extend the decomposition of HOT into first vs. higher order to a bilateral context, defining

$$\mathrm{HOT}_{ij}^{rs} = \mathrm{HOT}_{ij\,\text{order=1}}^{rs} + \mathrm{HOT}_{ij\,\text{order>1}}^{rs} + \mathrm{HOT}_{ij\,\text{mix}}^{rs},$$

where

$$\begin{aligned}
\mathrm{HOT}_{ij\,\text{order=1}}^{rs} &= \mathrm{HOT}_{i\,\text{order=1}}^{r} \times \mathrm{HOT}_{j\,\text{order=1}}^{s}, \\
\mathrm{HOT}_{ij\,\text{order>1}}^{rs} &= \mathrm{HOT}_{i\,\text{order>1}}^{r} \times \mathrm{HOT}_{j\,\text{order>1}}^{s}, \\
\mathrm{HOT}_{ij\,\text{mix}}^{rs} &= \mathrm{HOT}_{ij}^{rs} - \mathrm{HOT}_{ij\,\text{order=1}}^{rs} - \mathrm{HOT}_{ij\,\text{order>1}}^{rs}
\end{aligned}$$

Measuring cycle synchronization over time is not straightforward. A popular measure computes the negative pairwise absolute difference in growth rates, given by

$$\mathrm{SYNC1}_{ij,t}^{rs} = -|g_{i,t}^{r} - g_{j,t}^{s}|,$$

which was introduced for example by Kalemli-Özcan et al. (2013). An alternative is to compute the quasi correlation between sector growth rates, given by

$$\mathrm{SYNC2}_{ij,t}^{rs} = \frac{(g_{i,t}^{r} - \bar{g}_{i}^{r}) \times (g_{j,t}^{s} - \bar{g}_{j}^{s})}{\sigma_{i}^{r}\sigma_{j}^{s}},$$

where $\bar{g}_{i}^{r}$ and σ_{i}^{r} denote the mean and standard deviation of $g_{i,t}^{r}$. The measure was implemented among others in Duval et al. (2016). Both measures increase in synchronization.

It is straightforward to extend the other three measures of openness to a bilateral context. Since bilateral trade data are typically only available for intermediate goods, we define

$$\mathrm{X}_{ij}^{rs} = \left(\frac{\mathrm{PM}_{ij}^{rs} + \mathrm{PM}_{ji}^{rs}}{\mathrm{PVA}_{i}^{r} + \mathrm{PVA}_{j}^{r}}\right),$$

and

$$\phi_{ij}^{rs} = \left(\frac{\mathrm{PM}_{ij}^{rs} \times \mathrm{PM}_{ji}^{rs}}{\mathrm{PM}_{ii}^{rs} \times \mathrm{PM}_{jj}^{rs}}\right)^{1/2}.$$

Trade in Value Added is naturally bilateral inasmuch as it decomposes exports. In particular, TiVA_{ij}^r is defined by equation (6) omitting $\mathbf{1}$. We define:

$$\text{T}_{ij}^{rs}(\text{VA}) = \frac{\text{TiVA}_{ij}^r}{\text{PVA}_i^r} \times \frac{\text{TiVA}_{ji}^s}{\text{PVA}_j^s}.$$

We explore the correlation between synchronization and openness by estimating

$$\text{SYNC}_{ij,t}^{rs} = \alpha_{ij}^{rs} + \gamma_t + \beta_1 \ln \text{HOT}_{ij,t}^{rs} + \beta_2 \ln \text{X}_{ij,t}^{rs} + \beta_3 \ln \phi_{ij,t}^{rs} + \beta_4 \ln \text{T}_{ij,t}^{rs}(\text{VA}) + \varepsilon_{ij,t}^{rs}, \quad (11)$$

The fixed effects in equation (11) are very general as they are specific to each country *and* sector pair (i,j,r,s). Following the literature, measures of openness enter in logarithms. Table 6 report the estimates of equation (11) for both measures of synchronization, focusing first on HOT, on its sub-components, and then including controls. The results depend somewhat on the measure of synchronization used: SYNC1 implies that β_1 is actually negative and significant, whereas it is positive and significant using SYNC2. However, the high order component $\text{HOT}_{ij\,\text{order}>1}^{rs}$ is systematically positive and significant, an indication that focusing on first-order trade linkages is insufficient to capture shock propagation. $\text{HOT}_{ij\,\text{order}>1}^{rs}$ continues to enter with a positive and significant coefficient irrespective of the controls. Table 7 reports the estimates corresponding to univariate versions of equation ((11)) where each measure of openness is included one by one: High order linkages as measured by $\text{HOT}_{ij\,\text{order}>1}^{rs}$ are the only measure that correlates systematically with synchronization: All other openness measures enter with an unstable or a negative and significant coefficient. These results explain why such sector-level cross-country bilateral regressions have not been successfully performed yet: The right measure of the international propagation of foreign shocks was not available until now.

5 Conclusion

We propose a new measure of openness based on high order linkages, labeled HOT. The measure captures exposure to foreign shocks. It is computable for all sectors with available international input-output data, including services. According to HOT, sectors are relatively open on average, a few are very closed and a few are very open. This is dramatically different from the distributions of conventional measures of openness, which imply that most of the world is closed except for a few very open sectors in specific open countries. HOT implies a ranking of country openness that is not dissimilar to the existing consensus; but it is very different across sectors, with many more open sectors, especially services.

In an international model of intermediate trade and supply shocks, HOT is (close to) proportional to the response of output to foreign shocks. Simulations of the model suggests this property does not extend to conventional alternative measures of openness, including existing ones that account for high order linkages. This happens because HOT isolates the component of a sector's output that is affected by foreign shocks, at any order. Standard measures are often focused on direct trade (like exports, or implicit trade costs) or if they focus on high order linkages they typically decompose exports, rather than output. By construction they do not have much to say about the response of output. In a cross-country cross-sector context we show that our measure correlates significantly and positively with production, growth, and synchronization. None of the other standard measures of openness do.

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Table 1: Correlations

	HOT_i^r	ϕ_i^r	X_i^r	$\text{T}_i^r(\text{X})$	$\text{T}_i^r(\text{VA})$
			Entire sample		
HOT_i^r	1				
ϕ_i^r	0.061	1			
X_i^r	0.388	0.036	1		
$\text{T}_i^r(\text{X})$	-0.013	-0.003	-0.003	1	
$\text{T}_i^r(\text{VA})$	0.325	0.030	0.677	-0.004	1
			By country		
HOT_i^r	1				
ϕ_i^r	-0.045	1			
X_i^r	0.388	0.031	1		
$\text{T}_i^r(\text{X})$	-0.048	0.410	-0.023	1	
$\text{T}_i^r(\text{VA})$	0.271	0.019	0.971	-0.020	1
			By sector		
HOT_i^r	1				
ϕ_i^r	0.200	1			
X_i^r	0.674	0.148	1		
$\text{T}_i^r(\text{X})$	-0.053	-0.007	-0.028	1	
$\text{T}_i^r(\text{VA})$	0.783	0.213	0.753	-0.036	1

Note: The table reports the Pearson correlation coefficients between different measures of openness. The first panel reports correlations for the whole sample, the second panel reports the correlations of country averages, and the third panel the correlations of sector averages.

Table 2: Simulations: HOT and Value Added

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\ln \text{HOT}_{i,t}^r$	0.084	0.210	0.074	0.003	0.077	0.184	0.006	0.004
	(0.014)	(0.013)	(0.016)	(0.013)	(0.015)	(0.014)	(0.001)	(0.002)
$\ln \text{X}_{i,t}^r$		-0.678		2.154		0.019		-0.139
		(0.076)		(0.130)		(0.072)		(0.033)
$\ln \text{T}_{i,t}^r(\text{VA})$		1.674		-3.271		1.305		0.193
		(0.078)		(0.082)		(0.045)		(0.045)
$\ln \phi_{i,t}^r$		-0.059		-0.125		-0.036		0.024
		(0.006)		(0.007)		(0.006)		(0.002)
ρ	2.75	2.75	1	1	2.75	2.75	0.5	0.5
ϵ	1.5	1.5	1.5	1.5	1	1	0.5	0.5
ψ	2	2	2	2	2	2	2	2
Obs.	1,818	1,645	1,816	1,640	1,818	1,653	1,818	1,660

Note: The dependent variable is simulated $\ln \text{V}_{i,t}^r$. All the regressors are defined in the text. Standard errors in parentheses.

Table 3: Simulations: other measures of openness and Value Added

	(1)	(2)	(3)	(4)
$\ln \mathrm{X}^r_{i,t}$	-0.882	-1.821	-0.669	-0.088
	(0.063)	(0.119)	(0.063)	(0.011)
Obs.	2,000	2,000	2,000	2,000
$\ln \mathrm{T}^r_{i,t}(\mathrm{VA})$	1.087	-2.420	1.254	-0.099
	(0.067)	(0.061)	(0.039)	(0.012)
Obs.	2,018	2,018	2,018	2,018
$\ln \phi^r_{i,t}$	-0.083	-0.103	-0.068	0.022
	(0.005)	(0.008)	(0.006)	(0.001)
Obs.	1,818	1,818	1,818	1,818
ρ	2.75	1	2.75	0.5
ϵ	1.5	1.5	1	0.5
ψ	2	2	2	2

Note: The dependent variable is simulated $\ln \mathrm{V}^r_{i,t}$. All the regressors are defined in the text. Standard errors in parentheses.

Table 4: Value Added Estimations

	All sectors (1)	All sectors (2)	All sectors (3)	Agr (4)	Mfg (5)	Ser (6)
			Fixed Effects Estimations			
HOT_i^r	0.265		0.701	0.177	0.849	0.639
	(0.078)		(0.091)	(0.284)	(0.125)	(0.153)
$\text{HOT}_{i\,\text{order}=1}^r$		0.249				
		(0.079)				
$\text{HOT}_{i\,\text{order}>1}^r$		0.487				
		(0.150)				
X_i^r			-0.232	-0.065	-0.188	-0.328
			(0.038)	(0.105)	(0.059)	(0.062)
ϕ_i^r			0.015	-0.052	0.045	-0.045
			(0.031)	(0.117)	(0.042)	(0.048)
$\text{T}_i^r(\text{VA})$			-0.150	0.001	-0.133	-0.201
			(0.036)	(0.065)	(0.040)	(0.114)
Obs.	30,958	30,958	30,958	1,875	11,971	13,998
			First Difference Estimations			
HOT_i^r	0.114		0.664	0.259	0.654	0.830
	(0.042)		(0.097)	(0.179)	(0.094)	(0.215)
$\text{HOT}_{i\,\text{order}=1}^r$		0.116				
		(0.041)				
$\text{HOT}_{i\,\text{order}>1}^r$		0.397				
		(0.079)				
X_i^r			-0.311	-0.165	-0.226	-0.461
			(0.047)	(0.119)	(0.046)	(0.080)
ϕ_i^r			0.039	-0.048	0.050	0.015
			(0.011)	(0.036)	(0.016)	(0.012)
$\text{T}_i^r(\text{VA})$			-0.184	0.011	-0.138	-0.494
			(0.086)	(0.041)	(0.068)	(0.260)
Obs.	28,877	28,877	28,877	1,750	11,164	13,060

Note: The dependent variable is the logarithm of real value added in PPP USD. All Fixed Effects Estimations include country $\times$ sector fixed effects and year effects. Robust standard errors in parentheses, clustered at country-sector level.

Table 5: Growth Estimations

	All sectors (1)	All sectors (2)	All sectors (3)	Agr (4)	Mfg (5)	Ser (6)
			OLS estimations			
Initial V.A.	-0.018	-0.019	-0.019	-0.010	-0.015	-0.029
	(0.002)	(0.002)	(0.002)	(0.005)	(0.002)	(0.003)
HOT_i^r	0.046		0.062	-0.016	0.107	0.018
	(0.007)		(0.012)	(0.041)	(0.018)	(0.020)
$\text{HOT}_{i\,\text{order}=1}^r$		0.044				
		(0.008)				
$\text{HOT}_{i\,\text{order}>1}^r$		0.081				
		(0.016)				
X_i^r			-0.009	0.010	-0.023	0.007
			(0.004)	(0.024)	(0.006)	(0.008)
ϕ_i^r			0.002	-38.9	0.002	0.001
			(0.001)	(22)	(0.001)	(0.001)
$\text{T}_i^r(\text{VA})$			-0.198	-0.0381	-0.413	0.581
			(0.330)	(0.820)	(0.210)	(1.10)
Obs.	2,063		2,063	125	798	933
			IV estimations			
Initial V.A.	-0.023			-0.032	-0.017	-0.032
	(0.002)			(0.014)	(0.003)	(0.004)
HOT_i^r	0.263			0.359	0.234	0.248
	(0.027)			(0.206)	(0.038)	(0.043)
Anderson-Rubin:						
Statistic	101.69			11.49	37.11	33.80
p-value	<0.001			<0.001	<0.001	<0.001
Confidence Sets	[0.214, 0.320]			[0.139, $+\infty$]	[0.166, 0.318]	[0.172, 0.344]
Obs.	2,063			125	798	933

Note: The dependent variable is the growth of real value added and Initial V.A. denotes its initial value, both in PPP USD. All variables are averaged over the whole sample period. All regressions include sector and country fixed effects. Robust standard errors in parentheses, clustered at country-sector level. All the coefficients and standard errors of the coefficient estimates on ϕ_i^r have been multiplied by 10,000 and on $\text{T}_i^r(\text{VA})$ by 100 for legibility.

Table 6: Synchronization: Absolute Difference and Quasi-Correlation

Dep. Var.	SYNC1 (1)	SYNC1 (2)	SYNC1 (3)	SYNC2 (4)	SYNC2 (5)	SYNC2 (6)
HOT	-0.160			0.554		
	(0.013)			(0.062)		
$\mathrm{HOT}_{\text{order}=1}$		0.002	0.017		-0.008	-0.025
		(0.007)	(0.008)		(0.036)	(0.040)
$\mathrm{HOT}_{\text{order}>1}$		0.089	0.080		0.221	0.244
		(0.005)	(0.006)		(0.024)	(0.026)
$\mathrm{HOT}_{\text{mix}}$		-0.118	0.003		0.258	0.415
		(0.014)	(0.016)		(0.070)	(0.077)
X			-0.258			-0.687
			(0.008)			(0.033)
ϕ			0.155			0.385
			(0.007)			(0.032)
T(VA)			-0.290			-0.685
			(0.008)			(0.034)
Obs.	27,113,037	26,233,038	22,608,382	27,113,037	26,233,038	22,608,382

Note: The regressions are performed with reghdfe in STATA, which allows for multiple level fixed effects (see Correia, 2017). Estimations include (i, j, r, s) fixed effects and year effects. Robust standard errors in parentheses, clustered at country-sector pair level. All coefficients and standard errors have been multiplied by 100 for legibility.

Table 7: Synchronization: Other measures of openness

	(1)	(2)	(3)	(4)	(5)	(6)
			Dependent Variable: SYNC1			
$\text{HOT}_{\text{order}=1}$	-0.041					
	(0.006)					
$\text{HOT}_{\text{order}>1}$		0.080				
		(0.005)				
HOT_{mix}			-0.043			
			(0.011)			
X				-0.144		
				(0.004)		
ϕ					-0.085	
					(0.005)	
T(VA)						-0.282
						(0.007)
			Dependent Variable: SYNC2			
$\text{HOT}_{\text{order}=1}$	0.056					
	(0.029)					
$\text{HOT}_{\text{order}>1}$		0.247				
		(0.022)				
HOT_{mix}			0.253			
			(0.052)			
X				-0.488		
				(0.018)		
ϕ					-0.188	
					(0.022)	
T(VA)						-0.713
						(0.028)
Obs.	26,327,681	27,013,538	27,108,167	28,752,051	24,817,513	29,074,170

Note: The regressions are performed with reghdfe in STATA, which allows for multiple level fixed effects (see Correia, 2017). Estimations include (i, j, r, s) fixed effects and year effects. Robust standard errors in parentheses, clustered at country-sector pair level. All coefficients and standard errors have been multiplied by 100 for legibility.

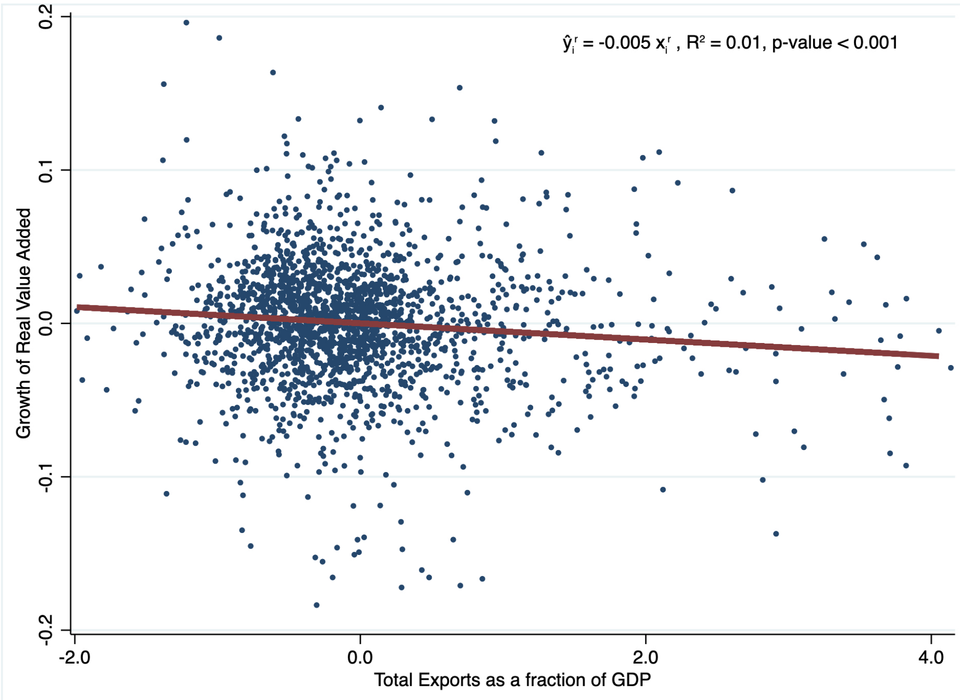

Figure 1: Sector-level growth against Exports as a fraction of GDP, after controlling for country-level fixed effects.

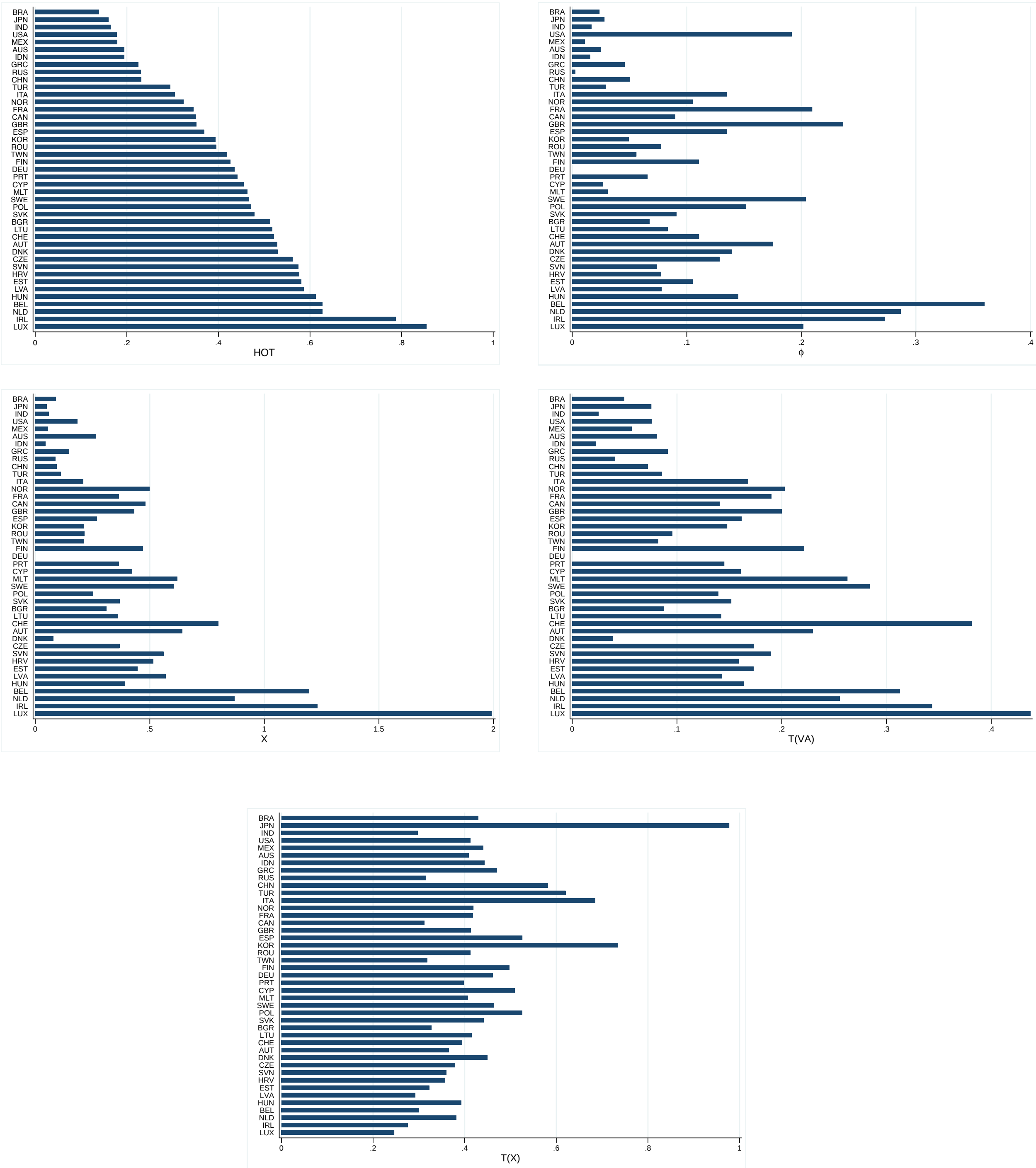

Figure 2: Median sector values of HOT_i^r, ϕ_i^r, X_i^r, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_i^r(\mathrm{X})$ by country in 2014.

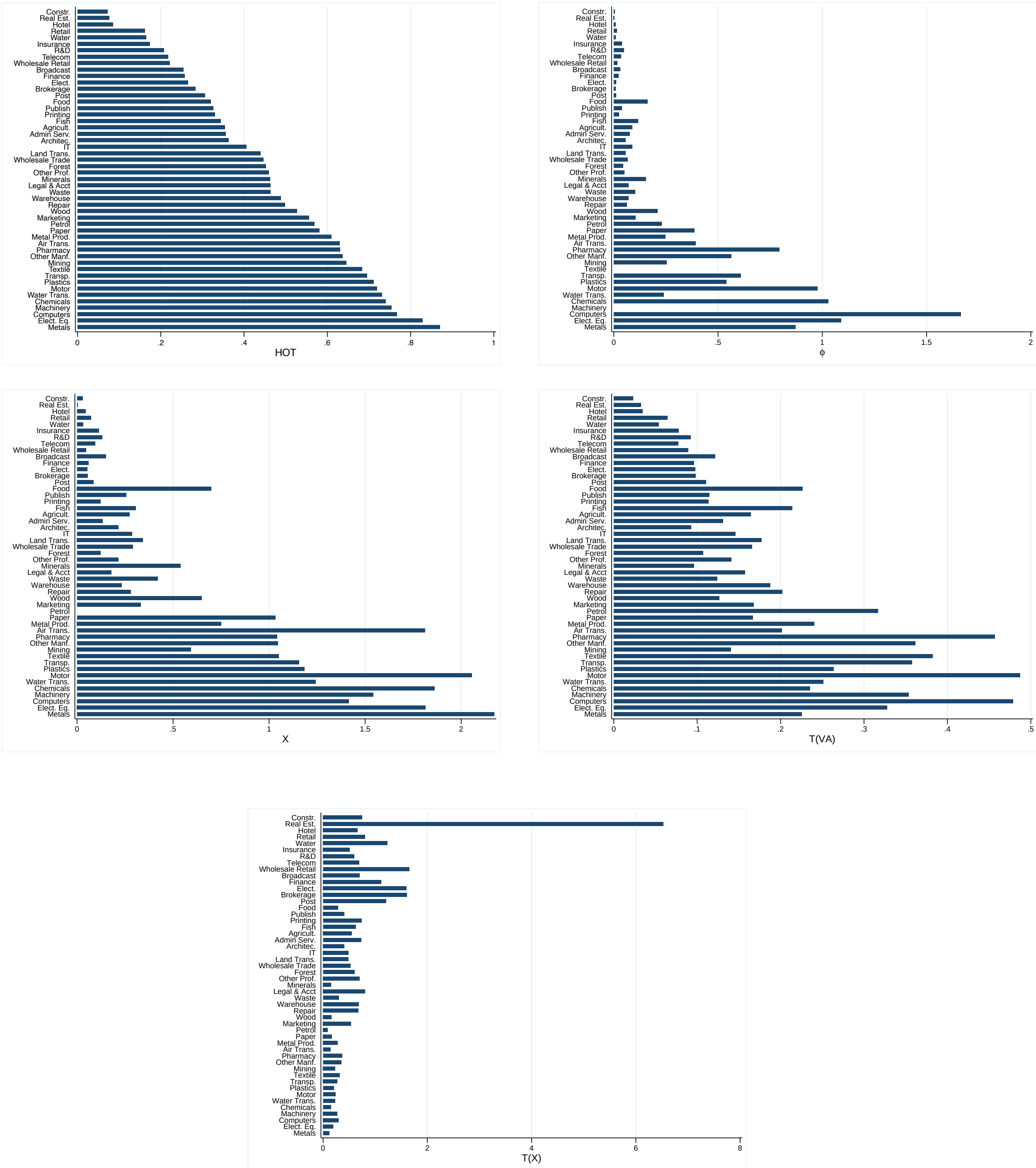

Figure 3: Median country value of HOT_i^r, ϕ_i^r, X_i^r, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_i^r(\mathrm{X})$ by sector in 2014.

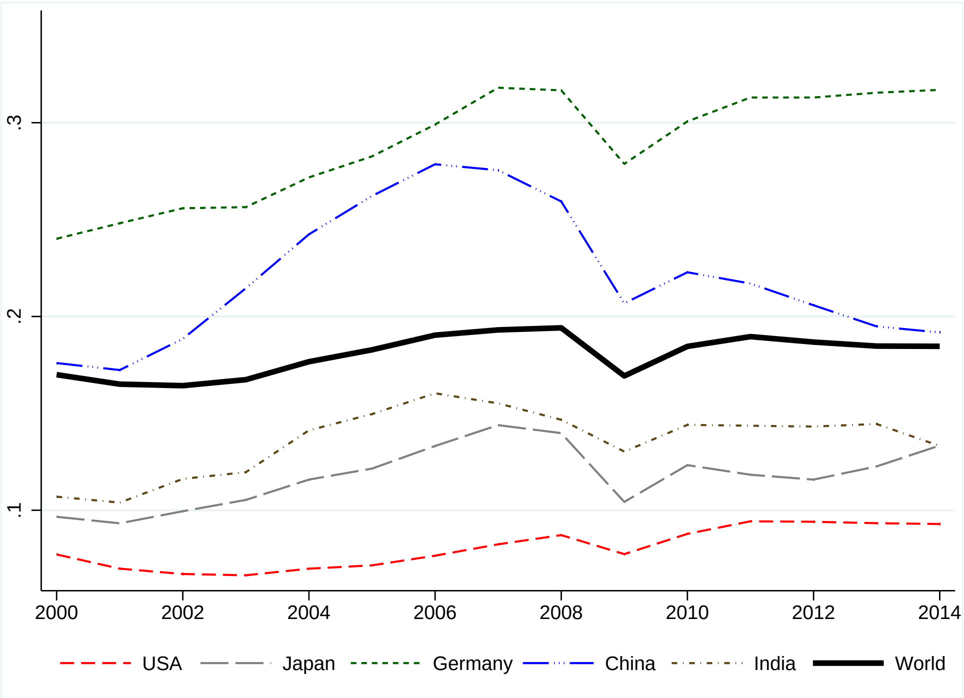

Figure 4: HOT is depicted over time for five countries and the World. Country values are value added weighted averages of sector level HOT_i^r. Worldwide HOT is a GDP weighted average of country-level HOT. Value added is converted in USD at PPP exchange rate.

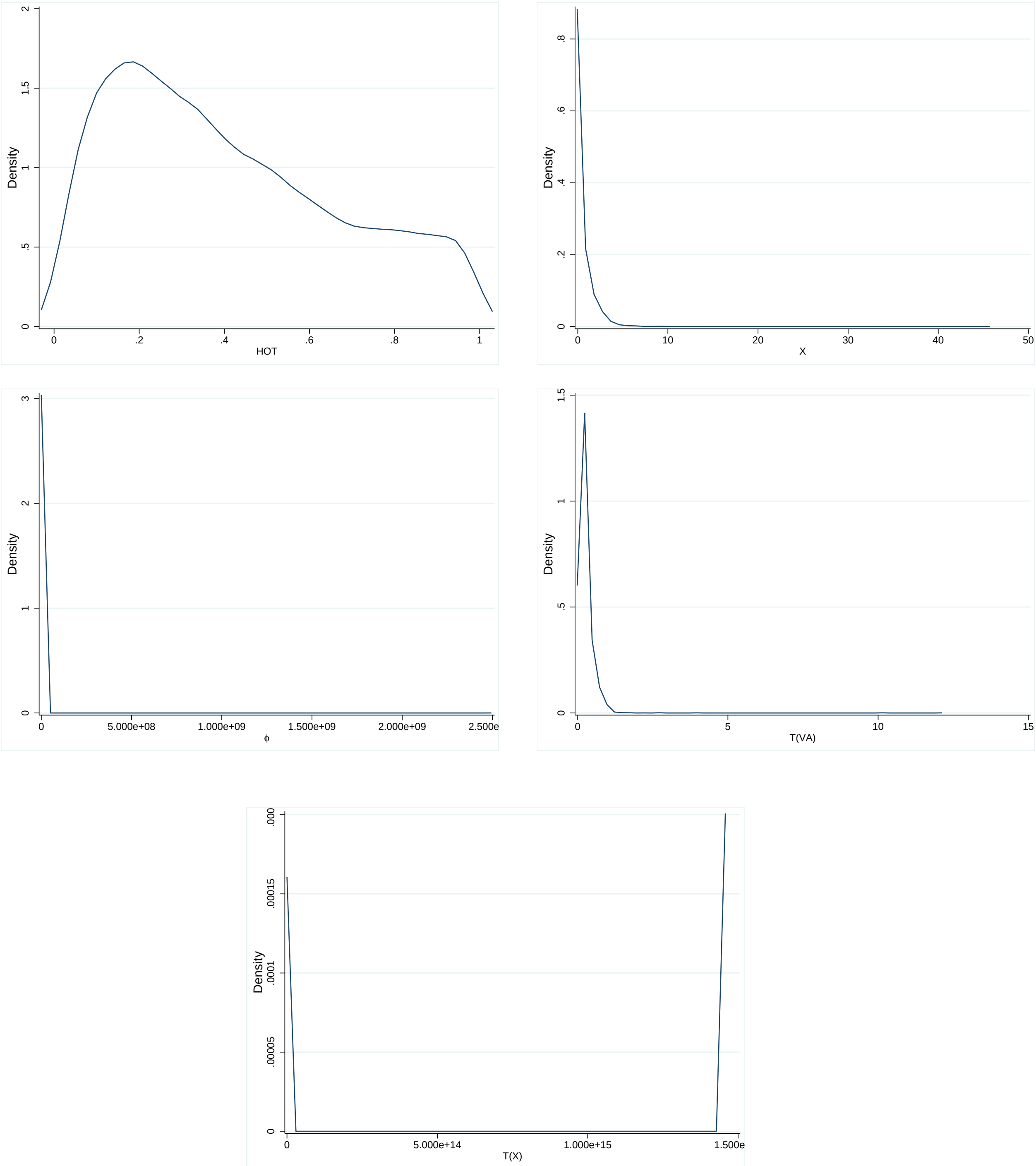

Figure 5: Densities of HOT_i^r, X_i^r, ϕ_i^r, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_i^r(\mathrm{X})$.

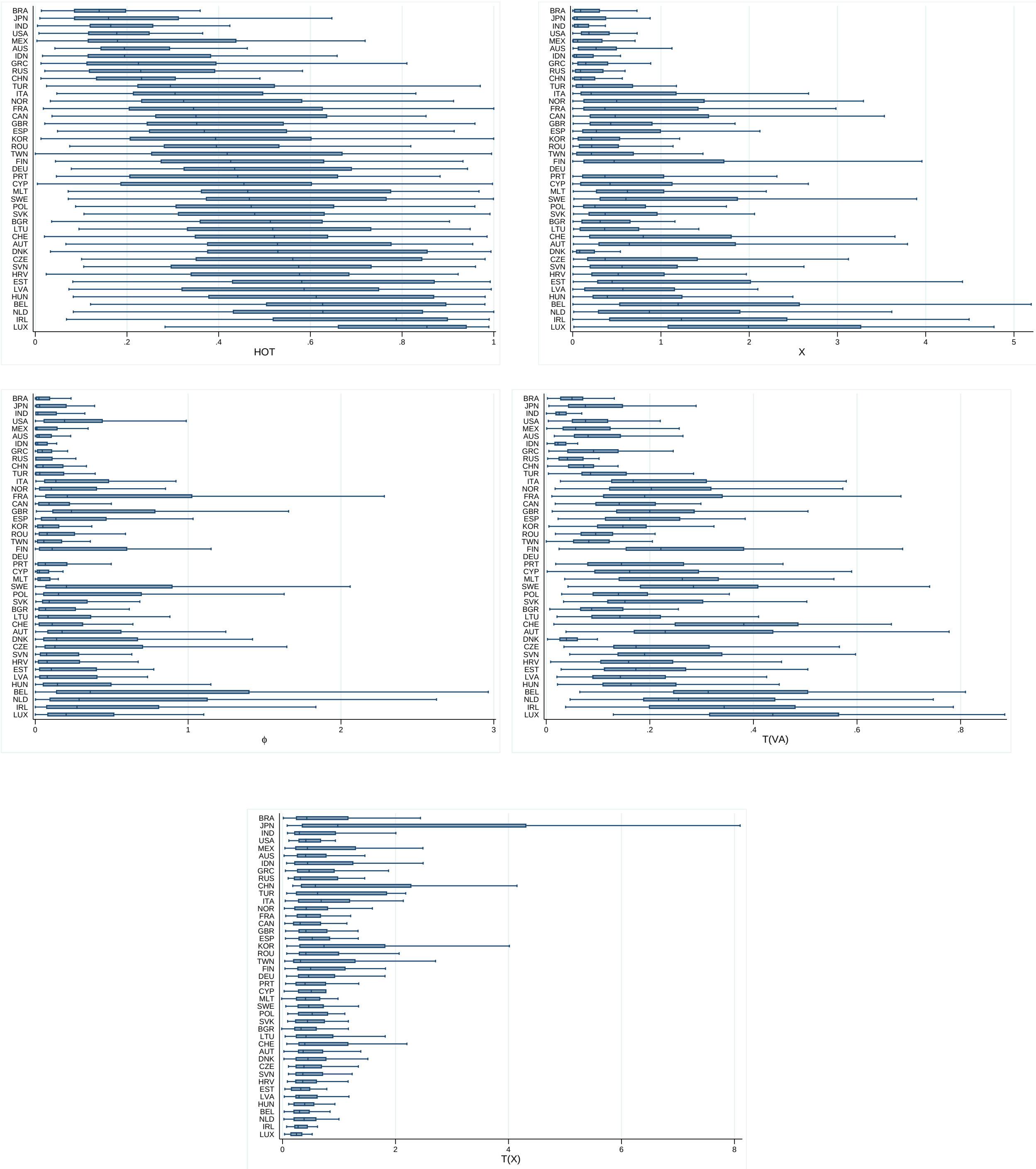

Figure 6: Dispersion of HOT_i^r, X_i^r, ϕ_i^r, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_i^r(\mathrm{X})$ across sectors for each country in 2014. The mid-point is the median, the thick segment is the interquartile range, and the whiskers are extreme values.

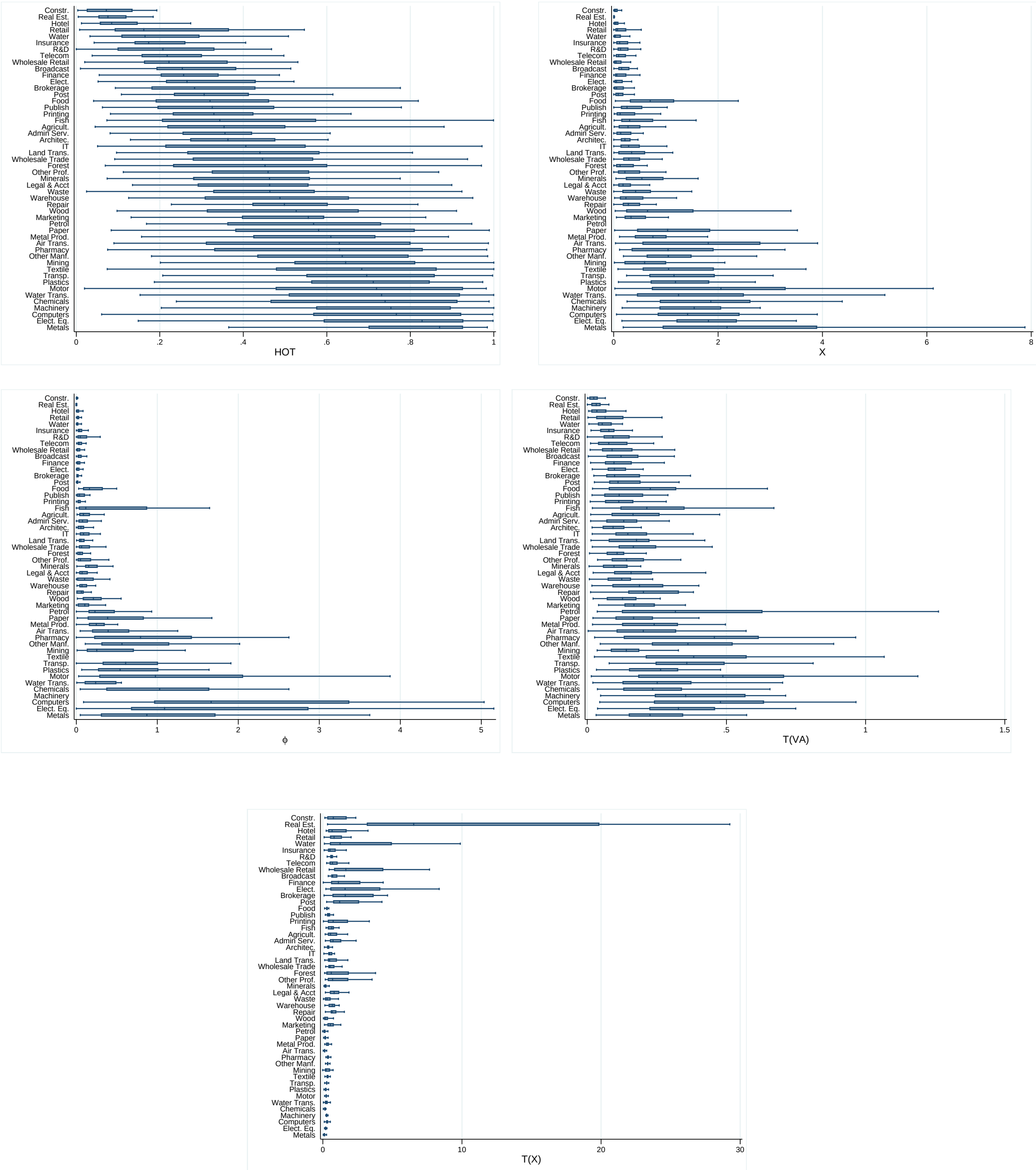

Figure 7: Dispersion of HOT_i^r, X_i^r, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_i^r(\mathrm{X})$ across countries for each sector in 2014. The mid-point is the median, the thick segment is the interquartile range, and the whiskers are extreme values.

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Appendix A

This appendix summarizes the key steps in the derivation of the influence matrix from Huo et al. (2021). All equilibrium conditions are expressed in deviations from the steady state, denoted with time subscripts and ln-deviations. Market clearing becomes

$$\ln \mathrm{P}_{i,t}^r + \ln \mathrm{Y}_{i,t}^r = \sum_j \sum_s \frac{ac_{ij}^r \, \mathrm{P}_j^c \, \mathrm{C}_j}{\mathrm{P}_i^r \, \mathrm{Y}_i^r} \frac{\eta^s \, \mathrm{P}_j^s \, \mathrm{Y}_j^s}{\mathrm{P}_j^c \, \mathrm{C}_j} (\ln \mathrm{P}_{j,t}^s + \ln \mathrm{Y}_{j,t}^s + \ln \pi_{ij,t}^r)$$
$$+ \sum_j \sum_s \frac{\mathrm{P}_j^s \, \mathrm{Y}_j^s \, a_{ij}^{rs}}{\mathrm{P}_i^r \, \mathrm{Y}_i^r} (\ln \mathrm{P}_{j,t}^s + \ln \mathrm{Y}_{j,t}^s + \ln \xi_{ij,t}^{rs}),$$

where in addition

$$\ln \pi_{ij,t}^r = (1-\rho) \sum_{k,l} ac_{kj}^l (\ln \mathrm{P}_{i,t}^r - \ln \mathrm{P}_{k,t}^l),$$
$$\ln \xi_{ij,t}^{rs} = (1-\epsilon) \sum_{k,l} \frac{a_{kj}^{ls}}{1-\eta^s} (\ln \mathrm{P}_{i,t}^r - \ln \mathrm{P}_{k,t}^l).$$

We now introduce matrices of relevant steady state ratios that help define the equilibrium.

Definition.

$\mathbf{A}^m$ *is the matrix with typical element the direct requirement coefficient* $a_{ij}^{rs} = \frac{\mathrm{P}_{ij}^{rs} \mathrm{M}_{ij}^{rs}}{\mathrm{P}_j^s \mathrm{Y}_j^s} = (1-\eta^s)\frac{\mathrm{P}_{ij}^{rs} \mathrm{M}_{ij}^{rs}}{\mathrm{P}_j^s \mathrm{M}_j^s}$ *the share of output in* (j, s) *that is produced using intermediate inputs from* (i, r).

$\mathbf{A}^c$ *is the matrix with typical element* $ac_{ij}^r = \frac{\mathrm{P}_{ij}^r \mathrm{C}_{ij}^r}{\mathrm{P}_j^c \mathrm{C}_j}$ *the expenditure share of country* j*'s final consumption that is spent on final goods produced in* (i, r).

$\mathbf{B}^m$ *is the matrix with typical element the allocation coefficient* $b_{ij}^{rs} = \frac{(1-\eta^s) \mathrm{P}_j^s \mathrm{Y}_j^s \xi_{ij}^{rs}}{\mathrm{P}_i^r \mathrm{Y}_i^r} = \frac{\mathrm{P}_{ij}^{rs} \mathrm{M}_{ij}^{rs}}{\mathrm{P}_i^r \mathrm{Y}_i^r}$ *the share of output in source sector* (i, r) *that is used as intermediate input in* (j, s).

$\mathbf{B}^c$ *is the matrix with typical element* $bc_{ij}^r = \frac{\pi_{ij}^r \mathrm{P}_j^c \mathrm{C}_j}{\mathrm{P}_i^r \mathrm{Y}_i^r} = \frac{\mathrm{P}_{ij}^r \mathrm{C}_{ij}^r}{\mathrm{P}_i^r \mathrm{Y}_i^r}$ *the share of output in source sector* (i, r) *used as final consumption in country* j.

$\boldsymbol{\Upsilon}$ *is the matrix with typical element* $\upsilon_i^r = \frac{\eta^r \mathrm{P}_i^r \mathrm{Y}_i^r}{\mathrm{P}_i^c \mathrm{C}_i}$ *the share of nominal value added in* (i, r) *in total nominal consumption in country* i.

Rewriting the resource constraint in matrix algebra making use of these definitions yields

$$\ln \mathbf{P}_t + \ln \mathbf{Y}_t = (\mathbf{B}^c \boldsymbol{\Upsilon} + \mathbf{B}^m)(\ln \mathbf{P}_t + \ln \mathbf{Y}_t) + (1-\rho)\left[\text{diag}(\mathbf{B}^c \mathbf{1}) - \mathbf{B}^c (\mathbf{A}^c)^\top\right] \ln \mathbf{P}_t$$
$$+ (1-\epsilon)\left[\text{diag}(\mathbf{B}^m \mathbf{1}) - \mathbf{B}^m (\mathbf{I}-\boldsymbol{\eta})^{-1} (\mathbf{A}^m)^\top\right] \ln \mathbf{P}_t, \tag{A.12}$$

which implies an equilibrium relation between prices and quantities. In deviations from the steady state, the production function can be rewritten as

$$\ln \mathbf{Y}_t = \ln \mathbf{Z}_t + \boldsymbol{\eta}\boldsymbol{\alpha} \ln \mathbf{H}_t + (\mathbf{I}-\boldsymbol{\eta}) \ln \mathbf{M}_t. \tag{A.13}$$

Equilibrium labor input is given by

$$\ln \mathbf{H}_t = \frac{\psi}{1+\psi} \ln \mathbf{Y}_t + \frac{\psi}{1+\psi} (\mathbf{I} - (\mathbf{A}^c)^\top \otimes \mathbf{1}) \ln \mathbf{P}_t, \tag{A.14}$$

where $\ln \mathbf{P}_t^c = [(\mathbf{A}^c)^\top \otimes \mathbf{1}] \ln \mathbf{P}_t$. Market clearing in the intermediate input market implies

$$\ln \mathbf{M}_t = \ln \mathbf{Y}_t + \left(\mathbf{I} - (\mathbf{I}-\boldsymbol{\eta})^{-1} (\mathbf{A}^m)^\top\right) \ln \mathbf{P}_t. \tag{A.15}$$

Combining equations (A.12)-(A.13)-(A.14)-(A.15) yields the expression for the response of real output $\ln \mathbf{Y}_t$ in the text, where we define:

$$\boldsymbol{\Lambda} = \left[\mathbf{I} - \frac{\psi}{1+\psi}\boldsymbol{\eta}\boldsymbol{\alpha}\left(\mathbf{I} + \left(\mathbf{I} - (\mathbf{A}^c)^\top \otimes \mathbf{1}\right)\mathcal{P}\right) - (\mathbf{I}-\boldsymbol{\eta})\left(\mathbf{I} + \left(\mathbf{I} - (\mathbf{I}-\boldsymbol{\eta})^{-1}(\mathbf{A}^m)^\top\right)\mathcal{P}\right)\right],$$

$$\mathcal{P} = -\left(\mathbf{I} - \mathcal{M}\right)^+ \left(\mathbf{I} - \mathbf{B}^c \boldsymbol{\Upsilon} - \mathbf{B}^m\right),$$

and

$$\mathcal{M} = \mathbf{B}^c\boldsymbol{\Upsilon} + \mathbf{B}^m + (1-\rho)\left(\text{diag}(\mathbf{B}^c\mathbf{1}) - \mathbf{B}^c(\mathbf{A}^c)^\top\right) + (1-\epsilon)\left(\text{diag}(\mathbf{B}^m\mathbf{1}) - \mathbf{B}^m(\mathbf{I}-\boldsymbol{\eta})^{-1}(\mathbf{A}^m)^\top\right).$$

The + sign stands for the Moore-Penrose inverse as $\mathbf{I} - \mathcal{M}$ is not invertible. See Huo et al. (2021).

Appendix B

This appendix derives the expressions needed to characterize the responses of all four measures of openness to supply shocks. We start with the responses of $\ln \mathrm{P}^r_{i,t}\,\mathrm{Y}^r_{i,t}$, $\ln \mathrm{P}^{rs}_{ij,t}\,\mathrm{M}^{rs}_{ij,t}$, and $\ln \mathrm{P}^r_{ij,t}\,\mathrm{C}^r_{ij,t}$, and then turn to the expressions for the four measures of openness in terms of the fundamentals of the model.

Combining equations (A.12) and the reduced form expression for real output yields the response of prices to supply shocks:

$$\ln \mathbf{P}_t = \mathcal{P} \ln \mathbf{Y}_t$$

It follows the response of nominal output is given by

$$\ln \mathbf{PY}_t = (\mathcal{P} + \mathbf{I})\mathbf{\Lambda}^{-1} \ln \mathbf{Z}_t$$

From the production function, it is immediate that

$$\ln \mathbf{PM}_t = \ln \mathbf{PY}_t = (\mathcal{P} + \mathbf{I})\mathbf{\Lambda}^{-1} \ln \mathbf{Z}_t.$$

This characterizes the $\mathrm{NR} \times 1$ vector of the responses of nominal intermediate input, with element $\ln \mathrm{P}^r_{i,t}\,\mathrm{M}^r_{i,t}$. Furthermore, in equilibrium,

$$\mathrm{P}^{sr}_{ji}\,\mathrm{M}^{sr}_{ji} = \xi^{sr}_{ji}\,\mathrm{P}^r_i\,\mathrm{M}^r_i\,.$$

It follows that in deviations from the steady state,

$$\begin{aligned}\ln \mathrm{P}^{sr}_{ji,t}\,\mathrm{M}^{sr}_{ji,t} &= \ln \xi^{sr}_{ji,t} + \ln \mathrm{P}^r_{i,t}\,\mathrm{M}^r_{i,t} \\ &= (1-\epsilon) \sum_{k,l} \frac{a^{ls}_{kj}}{1-\eta^r}(\ln \mathrm{P}^s_{j,t} - \ln \mathrm{P}^l_{k,t}) + \ln \mathrm{P}^r_{i,t}\,\mathrm{M}^r_{i,t},\end{aligned}$$

which, along with the equations for $\ln \mathrm{P}^r_{i,t}\,\mathrm{M}^r_{i,t}$ and $\ln \mathrm{P}^s_{j,t}$ completes the characterization of $\ln \mathrm{P}^{sr}_{ji,t}\,\mathrm{M}^{sr}_{ji,t}$ and $\ln \mathrm{P}^{sr}_{jj,t}\,\mathrm{M}^{sr}_{jj,t}$.

With financial autarky, nominal final expenditures in deviations from the steady state are given by

$$\ln \mathrm{P}^c_{i,t}\, \mathrm{C}_{i,t} = \frac{\sum_r \eta^r\, \mathrm{P}^r_i\, \mathrm{Y}^r_i \ln \mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t}}{\mathrm{P}^c_i\, \mathrm{C}_i}$$
$$= \sum_r \upsilon^r_i \ln \mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t},$$

where υ^r_i is the typical element of $\boldsymbol{\Upsilon}$. Furthermore, in equilibrium

$$\mathrm{P}^r_{ji}\, \mathrm{C}^r_{ji} = \pi^r_{ji}\, \mathrm{P}^c_i\, \mathrm{C}_i,$$

so that in deviations from the steady state,

$$\ln \mathrm{P}^r_{ji,t}\, \mathrm{C}^r_{ji,t} = \ln \pi^r_{ji,t} + \ln \mathrm{P}^c_{i,t}\, \mathrm{C}_{i,t}$$
$$= (1-\rho) \sum_{k,l} ac^l_{kj} (\ln \mathrm{P}^r_{j,t} - \ln \mathrm{P}^l_{k,t}) + \ln \mathrm{P}^c_{i,t}\, \mathrm{C}_{i,t},$$

which, along with the equations for $\ln \mathrm{P}^c_{i,t}\, \mathrm{C}_{i,t}$ and $\ln \mathrm{P}^r_{j,t}$ completes the derivation of $\ln \mathrm{P}^r_{ji,t}\, \mathrm{C}^r_{ji,t}$ and $\ln \mathrm{P}^r_{jj,t}\, \mathrm{C}^r_{jj,t}$.

We can now express our measures of openness in terms of the fundamentals of the model. In deviations from the steady state, gross exports are given by

$$\ln \mathrm{X}^r_{i,t} = \frac{1}{\eta^r\, \mathrm{P}^r_i\, \mathrm{X}^r_i} \left[\sum_s \sum_{j\neq i} b^{rs}_{ij} (\ln \xi^{rs}_{ij,t} + \ln \mathrm{P}^s_{j,t}\, \mathrm{M}^s_{j,t}) + \sum_{j \neq i} bc^r_{ij} (\ln \pi^r_{ij,t} + \ln \mathrm{P}^c_{j,t}\, \mathrm{C}_{j,t}) \right] - \ln \mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t}$$

In deviations from the steady state the phiness of trade is given by

$$\ln \phi^r_{i,t} = \frac{1}{2} \sum_{j \neq i} \frac{(\phi^r_{ij})^{\frac{1}{2}}}{\phi^r_i} \left(\ln \Phi^r_{ij,t} - \ln \Phi^r_{ii,t} + \ln \Phi^r_{ji,t} - \ln \Phi^r_{jj,t} \right)$$
$$= \frac{1}{2} \sum_{j \neq i} \frac{(\phi^r_{ij})^{\frac{1}{2}}}{\phi^r_i} \left[\frac{\sum_s b^{rs}_{ij}}{\sum_s b^{rs}_{ij} + bc^r_{ij}} (\ln \xi^{rs}_{ij,t} + \ln \mathrm{P}^s_{j,t}\, \mathrm{M}^s_{j,t}) + \frac{bc^r_{ij}}{\sum_s b^{rs}_{ij} + bc^r_{ij}} (\ln \pi^r_{ij,t} + \ln \mathrm{P}^c_{j,t}\, \mathrm{C}_{j,t}) \right.$$
$$- \frac{\sum_s b^{rs}_{ii}}{\sum_s b^{rs}_{ii} + bc^r_{ii}} (\ln \xi^{rs}_{ii,t} + \ln \mathrm{P}^s_{i,t}\, \mathrm{M}^s_{i,t}) - \frac{bc^r_{ii}}{\sum_s b^{rs}_{ii} + bc^r_{ii}} (\ln \pi^r_{ii,t} + \ln \mathrm{P}^c_{i,t}\, \mathrm{C}_{i,t})$$
$$+ \frac{\sum_s b^{rs}_{ji}}{\sum_s b^{rs}_{ji} + bc^r_{ji}} (\ln \xi^{rs}_{ji,t} + \ln \mathrm{P}^s_{i,t}\, \mathrm{M}^s_{i,t}) + \frac{bc^r_{ji}}{\sum_s b^{rs}_{ji} + bc^r_{ji}} (\ln \pi^r_{ji,t} + \ln \mathrm{P}^c_{i,t}\, \mathrm{C}_{i,t})$$
$$\left. - \frac{\sum_s b^{rs}_{jj}}{\sum_s b^{rs}_{jj} + bc^r_{jj}} (\ln \xi^{rs}_{jj,t} + \ln \mathrm{P}^s_{j,t}\, \mathrm{M}^s_{j,t}) - \frac{bc^r_{jj}}{\sum_s b^{rs}_{jj} + bc^r_{jj}} (\ln \pi^r_{jj,t} + \ln \mathrm{P}^c_{j,t}\, \mathrm{C}_{j,t}) \right]$$

In deviations from the steady state, $\mathrm{T(VA)}$ can be written as

$$\begin{aligned}\ln \mathrm{T}^r_{i,t}(\mathrm{VA}) &= \frac{\sum_j \sum_s \lambda^{rs}_{ij}}{\sum_j \sum_s \lambda^{rs}_{ij}(bc^r_{ij} - bc^r_{ii})}(bc^r_{ij} \ln \mathrm{P}^r_{ij,t}\, \mathrm{C}^r_{ij,t} - bc^r_{ii} \ln \mathrm{P}^r_{ii,t}\, \mathrm{C}^r_{ii,t}) - \ln \mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t} \\ &= \frac{\sum_j \sum_s \lambda^{rs}_{ij} bc^r_{ij}}{\sum_j \sum_s \lambda^{rs}_{ij}(bc^r_{ij} - bc^r_{ii})}(\ln \mathrm{P}^r_{j,t}\, \mathrm{C}^r_{j,t} + \ln \pi^r_{ij,t}) \\ &- \frac{\sum_j \sum_s \lambda^{rs}_{ij} bc^r_{ii}}{\sum_j \sum_s \lambda^{rs}_{ij}(bc^r_{ij} - bc^r_{ii})}(\ln \mathrm{P}^r_{i,t}\, \mathrm{C}^r_{i,t} + \ln \pi^r_{ii,t}) - \ln \mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t}\end{aligned}$$

In deviations from the steady state, HOT is given by

$$\ln \mathrm{HOT}^r_{i,t} = \frac{1 - \mathrm{HOT}^r_i}{\mathrm{HOT}^r_i}\left(\ln \mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t} - \ln(\mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t})_{\mathrm{DOM}}\right)$$

where $\ln \mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t}$ is the typical element of the vector $(\mathcal{P} + \mathbf{I})\mathbf{\Lambda}^{-1} \ln \mathbf{Z}_t$, and $\ln(\mathrm{P}^r_{i,t}\, \mathrm{Y}^r_{i,t})_{\mathrm{DOM}}$ is computed using the block diagonal versions of the same matrices, focused on purely domestic linkages.

Appendix C

We present regressions performed on simulated data obtained for alternative parameter choices.

Table C.1: HOT Simulation results $\psi = 0.5$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\ln \mathrm{HOT}^r_{i,t}$	0.074	0.215	0.062	-0.008	0.064	0.180	0.001	-0.002
	(0.015)	(0.014)	(0.017)	(0.014)	(0.017)	(0.015)	(0.001)	(0.002)
$\ln \mathrm{X}^r_{i,t}$		-0.719		2.333		0.036		-0.124
		(0.079)		(0.141)		(0.075)		(0.022)
$\ln \mathrm{T(VA)}^r_{i,t}$		1.842		-3.457		1.362		0.157
		(0.075)		(0.088)		(0.044)		(0.033)
$\ln \phi^r_{i,t}$		-0.061		-0.127		-0.038		0.015
		(0.006)		(0.007)		(0.006)		(0.001)
ρ	2.75	2.75	1	1	2.75	2.75	0.5	0.5
ϵ	1.5	1.5	1.5	1.5	1	1	0.5	0.5
ψ	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Obs.	1,817	1,645	1,818	1,642	1,817	1,652	1,817	1,666

Note: The dependent variable is $\ln \mathrm{V}^r_{i,t}$. All the regressors are defined in the text. Standard errors in parentheses.

Table C.2: HOT Simulation results $\psi = 4$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\ln \mathrm{HOT}^r_{i,t}$	0.088	0.212	0.077	0.008	0.083	0.183	0.008	0.005
	(0.013)	(0.013)	(0.016)	(0.013)	(0.015)	(0.014)	(0.002)	(0.002)
$\ln \mathrm{X}^r_{i,t}$		-0.647		2.101		0.012		-0.133
		(0.075)		(0.125)		(0.070)		(0.036)
$\ln \mathrm{T(VA)}^r_{i,t}$		1.602		-3.209		1.286		0.188
		(0.079)		(0.080)		(0.046)		(0.048)
$\ln \phi^r_{i,t}$		-0.058		-0.122		-0.034		0.026
		(0.005)		(0.006)		(0.006)		(0.002)
ρ	2.75	2.75	1	1	2.75	2.75	0.5	0.5
ϵ	1.5	1.5	1.5	1.5	1	1	0.5	0.5
ψ	4	4	4	4	4	4	4	4
Obs.	1,817	1,642	1,818	1,642	1,817	1,649	1,818	1,656

Note: The dependent variable is $\ln \mathrm{V}^r_{i,t}$. All the regressors are defined in the text. Standard errors in parentheses.

Table C.3: Simulations of other openness measures with $\psi = 0.5$

	(1)	(2)	(3)	(4)
$\ln \mathrm{X}^r_{i,t}$	-0.844	-1.786	-0.650	-0.062
	(0.068)	(0.127)	(0.068)	(0.004)
Obs.	2,000	2,000	2,000	2,000
$\ln \mathrm{T(VA)}^r_{i,t}$	1.285	-2.494	1.310	-0.068
	(0.065)	(0.066)	(0.037)	(0.004)
Obs.	2,018	2,018	2,018	2,018
$\ln \phi^r_{i,t}$	-0.097	-0.107	-0.082	0.012
	(0.006)	(0.008)	(0.006)	(0.001)
Obs.	1,817	1,817	1,818	1,818
ρ	2.75	1	2.75	0.5
ϵ	1.5	1.5	1	0.5
ψ	0.5	0.5	0.5	0.5

Note: The dependent variable is $\ln \mathrm{V}^r_{i,t}$. All the regressors are defined in the text. Standard errors in parentheses.

Table C.4: Simulations of other openness measures with $\psi = 4$

	(1)	(2)	(3)	(4)
$\ln \mathrm{X}^r_{i,t}$	-0.895	-1.832	-0.676	-0.082
	(0.061)	(0.115)	(0.061)	(0.013)
Obs.	2,000	2,000	2,000	2,000
$\ln \mathrm{T(VA)}^r_{i,t}$	0.995	-2.391	1.228	-0.096
	(0.068)	(0.059)	(0.040)	(0.014)
Obs.	2,018	2,018	2,018	2,018
$\ln \phi^r_{i,t}$	-0.075	-0.099	-0.061	0.024
	(0.005)	(0.008)	(0.005)	(0.001)
Obs.	1,817	1,817	1,817	1,817
ρ	2.75	1	2.75	0.5
ϵ	1.5	1.5	1	0.5
ψ	4	4	4	4

Note: The dependent variable is $\ln \mathrm{V}^r_{i,t}$. All the regressors are defined in the text. Standard errors in parentheses.

Appendix D

D.1 HOT

The WIOD dataset spans the years 2000 – 2014. The data covers 44 countries (including a "rest of the world") and 56 sectors classified according to the International Standard Industrial Classification (ISIC) revision 4. The data are available at wiod.org. The method to calculate HOT is described in Section 2.1 and the method to calculate the instrument for HOT can be found in Section 4.2.

D.2 Value Added

Value added is converted in PPP USD and deflated using industry price levels of gross value added. Value added is in millions of national currency, price levels are indexed at 2010 = 100. All data are sourced from WIOD Socio-Economic Accounts (SEA). PPP USD exchange rates are sourced from the OECD.

D.3 Growth

Growth is constructed as the logarithm of sector level value added growth per employee, expressed in real PPP USD. Value added is in national currency and converted in USD at PPP exchange rate; it is deflated using industry price indices of gross value added. The data are sourced from WIOD SEA and the OECD.

D.4 Business Cycles Synchronization

SYNC1 is the demeaned product of real value added growth between country-sector pairs divided by each country-sector standard deviations. SYNC2 is measured as minus the absolute pairwise difference in the logarithm of real value added growth between country-sector pairs, measured each year. Value added is in national currency and converted in USD at PPP exchange rate. It is deflated using industry price indices. The source of the data are the WIOD SEA and the OECD.

D.5 Direct Trade measures: X and ϕ

Direct exports, X, are given by the ratio of total exports of intermediate and final goods to value added for each country-sector. Both numerator and denominator are expressed in current USD at PPP exchange rates. The bilateral version of X is given by the ratio of $\mathrm{PM}_{ij}^{rs} + \mathrm{PM}_{ji}^{rs}$ to $\mathrm{VA}_i^r + \mathrm{VA}_j^r$ for lack of data on bilateral trade in final goods. Both numerator and denominator are expressed in current PPP USD. ϕ is defined in section 2.4, and all its components are measured in PPP USD. Intermediate goods exports and final goods exports are obtained from WIOD's World Input-Output Tables. Value added is in national currency and converted in USD at PPP exchange rate. Value added is sourced from WIOD SEA and PPP exchange rate from the OECD.

D.6 Trade in Value Added (TiVA): T_i^r and T_{ij}^{rs}

The variants of TiVA used in the paper, $\mathrm{T}_i^r(\mathrm{X})$, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_{ij}^{rs}(\mathrm{VA})$ are described in section 2.2. TiVA measures are constructed using the Input-Output Tables from WIOD. $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_{ij}^{rs}(\mathrm{VA})$ are normalized by Value Added in real PPP USD. Value added is sourced from WIOD SEA and PPP exchange rate from the OECD. $\mathrm{T}_i^r(\mathrm{X})$ is normalized by gross exports which are the sum of intermediate and final exports found in World Input-Output Tables provided by WIOD.