DISCUSSION PAPER SERIES

DP17230

Measuring Openness

Jean Imbs and Laurent Pauwels

INTERNATIONAL MACROECONOMICS AND FINANCE

INTERNATIONAL TRADE AND REGIONAL ECONOMICS

MACROECONOMICS AND GROWTH

ISSN 0265-8003

Measuring Openness

Jean Imbs and Laurent Pauwels

Discussion Paper DP17230
Published 17 April 2022
Submitted 14 April 2022

Centre for Economic Policy Research
33 Great Sutton Street, London EC1V 0DX, UK
Tel: +44 (0)20 7183 8801
www.cepr.org

Measuring Openness

Abstract

We introduce a measure of exposure to foreign shocks -openness- that computes the fraction of output subjected to foreign shocks at any order. The measure is easy to obtain for any sector with input-output data; It implies that openness is much more prevalent than often thought, especially in services. Theoretically the new measure correlates systematically with the response of productivity to foreign shocks because it reflects high order linkages in output (rather than trade). Empirically it also correlates highly with productivity in an international sample of sector level data. None of these conclusions are true for conventional measures of openness.

JEL Classification: F15, F44, F62, C80

Keywords: Measurement of Openness, global value chains, shock propagation, growth, Productivity, Synchronization, Instrumenting Openness

Jean Imbs - jeanimbs@gmail.com
Paris School of Economics and CEPR

Laurent Pauwels - laurent.pauwels@sydney.edu.au
University of Sydney

Acknowledgements
We are grateful to Pol Antras, Richard Baldwin, Davin Chor, Romain Duval, Alessandro Ferrari, Lionel Fontagne, Robert Johnson, Leandro Magnusson, Kevin O'Rourke, Dani Rodrik, Mark Schaffer, Marcel Timmer, and audiences at ISI Delhi, ISB Hyderabad, Banco Central do Brasil, and NYU Abu Dhabi for comments on early versions. This paper supersedes "High Order Openness". All errors are our own.

Measuring Openness*

Jean Imbs †
NYUAD, PSE (CNRS), and CEPR

Laurent Pauwels‡
University of Sydney and CAMA, ANU

March 2022

Abstract

We introduce a measure of exposure to foreign shocks -openness- that computes the fraction of output subjected to foreign shocks at any order. The measure is easy to obtain for any sector with input-output data; It implies that openness is much more prevalent than often thought, especially in services. Theoretically the new measure correlates systematically with the response of productivity to foreign shocks because it reflects high order linkages in output (rather than trade). Empirically it also correlates highly with productivity in an international sample of sector level data. None of these conclusions are true for conventional measures of openness.

JEL Codes: F15, F44, F62, C80.

Keywords: Measurement of Openness, Global Value Chains, Shock Propagation, Growth, Productivity, Synchronization, Instrumenting Openness.

*We are grateful to Pol Antràs, Richard Baldwin, Davin Chor, Romain Duval, Alessandro Ferrari, Lionel Fontagné, Robert Johnson, Leandro Magnusson, Kevin O'Rourke, Dani Rodrik, Mark Schaffer, Marcel Timmer, and audiences at ISI Delhi, ISB Hyderabad, Banco Central do Brasil, and NYU Abu Dhabi for comments on early versions. This paper supersedes "High Order Openness". All errors are our own.

†Corresponding author: NYU Abu Dhabi, Saadiyat Island Campus, Abu Dhabi, UAE. Telephone: +971 26287653. Email (URL): jmi5@nyu.edu (www.jeanimbs.com).

‡The University of Sydney Business School, Darlington, NSW 2006, Australia. Email: laurent.pauwels@sydney.edu.au.

1 Introduction

Exposure to foreign shocks - openness - is typically measured with trade data. For example, the total values of exports or imports are often compared with value added, see Alcalá and Ciccone (2004). Trade in Value Added (TiVA) captures the integration of exports with the global value chain, see Johnson and Noguera (2012). The "phiness" of trade approximates trade costs from trade values normalized according to the gravity model, see Baldwin et al. (2003) or Head and Mayer (2004).

We introduce a measure of openness, high order trade linkages (HOT for short) that computes the fraction of output subjected to foreign shocks at any order. By definition, HOT is a decomposition of output rather than trade. This presents two advantages. First, HOT is easy to compute for any sector with input-output data, which includes activities that are customarily classified as closed to trade such as services.

The second advantage is theoretical. HOT is a far better measure of a sector's exposure to foreign shocks than existing alternatives. This happens because HOT reflects high order linkages (unlike exports normalized by value added X or the phiness of trade ϕ) and because it is defined as a decomposition of output (and not trade like TiVA). We motivate HOT in a multi-country, multi-sector model of intermediate trade, which we subject to combinations of domestic and foreign shocks. We simulate the responses of labor productivity at sector level, allowing for shock propagation via trade in final and intermediate goods. We then simulate the values of HOT, TiVA, X, and ϕ in response to the same shocks and ask which measure correlates most with the response of labor productivity. The only robust significant correlation is with HOT. In the model this happens because in response to foreign shocks, labor productivity and HOT are proportional for plausible parameter values. There is no such proportionality rules for any of the other conventional measures of openness.

Turning to the data, we present some stylized facts for HOT and compare them with conventional measures of openness. We characterize the distributions of openness across 50 sectors in 43 countries as implied by HOT, TiVA, X, and ϕ. We then document the correlates of each of these four measures across country-sectors, focusing in particular on labor productivity, growth, and synchronization. Such coverage is unattainable in firm-level data, which are sometimes used to inspect these correlations.[1] As the model implies, HOT is the only measure that displays a robust and significantly positive correlation with all three variables at sector level.

[1] 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).

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 and HOT takes high values close to one if most of the sector's gross output is in fact used across the border.[2]

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.

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.[3] 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 (0.18) or Real Estate (0.22). Services are consistently 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.

According to 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, see Johnson and Noguera (2012). 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

[2]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).

[3]The six public sectors are omitted. For details about WIOD, see Dietzenbacher et al. (2013). The 2016 release of WIOD is described in Timmer et al. (2016).

0 and 1. This is intuitive: while many sectors do not trade directly across the border, most sectors trade indirectly across a border.

These differences are interesting but they do not imply that HOT is a good measure of a sector's exposure to foreign shocks. To address this important question we turn to theory and simulate a multi-sector, multi-country model of international trade adapted from Huo et al. (2021). We calibrate the model to WIOD and subject each sector (outside of the US) to a combination of aggregate domestic and aggregate US shocks. We simulate the responses of value added per worker and the four measures of interest - HOT, TiVA, X, and ϕ. We use the resulting $50 \times 42 = 2{,}100$ simulated data points to evaluate in a regression setting which of the measures of openness is most correlated with the response of value added per worker. 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 propagation of foreign shocks.[4] And unlike TiVA, HOT summarizes the contribution of foreign shocks to *output*.

Of course 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), but rare or simply non-existent in cross-country sector level data. We first ask whether a sector openness correlates systematically with its productivity, a question many times asked in firm-level data.[5] Second we ask whether openness correlates with growth, a question that was first asked across countries and more recently at firm level.[6] Third and finally, we introduce a bilateral version of HOT and ask whether it correlates with the synchronization of business cycles at sector level.[7].

We document a systematic positive and significant correlation between HOT, labor productivity, growth, and synchronization at sector level. The estimates have the wrong sign and are unstable using conventional openness measures. Thus, provided openness is measured by HOT, we are able to confirm in international sector-level data what

[4] It is well-known that the Leontief inverse of input-output matrices characterizes the propagation of supply and demand shocks via intermediate trade, see for instance Acemoglu, Akcigit, and Kerr (2016).

[5] See among many others the seminal studies of Bernard and Jensen (1995, 1999, 2004) at firm level, or productivity enhancing reallocation effects in Amiti and Konings (2007), Topalova and Khandelwal (2011), Bernard et al. (2018), or De Loecker and Van Biesebroeck (2018)

[6] See for instance the survey by Baldwin et al. (2003) across countries, or Amiti and Konings (2007), Halpern et al. (2015) or Bøler et al. (2015) at firm level.

[7] 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)

was already known in some aggregate (and some firm-level) evidence. This is not true if openness is measured by any of its more conventional alternatives. 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 growing 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. The two become increasingly disconnected as supply chains integrate globally (see for instance Johnson and Noguera, 2012, Koopman et al., 2014, Bems and Kikkawa, 2019, 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.[8] What we know is that service trade as a whole has risen since the 1980s, without much of a commensurate fall in formal protection. Unsurprisingly, a large literature has deployed treasures of ingenuity to decompose this increase into its sector components. 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 services 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). Our contribution is to introduce a precise measure of openness for services that is readily available from input-output data, that does not depend on actually observed direct trade, and that correlates significantly with sector-level measures of productivity, growth, and synchronization.

The rest of the paper is structured as follows. Section 2 describes the methodology implemented to compute HOT and discusses some stylized facts in comparison with

[8] 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.

TiVA, X, and ϕ. Section 3 presents a multi-country model of shock propagation and asks in simulated data which measure of openness best reflects exposure to foreign shocks. Section 4 asks the same question in actual data. Section 5 concludes.

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

$$\mathrm{PY}_i^r = \sum_s \sum_j \mathrm{PM}_{ij}^{rs} + \sum_j \mathrm{PC}_{ij}^r, \tag{1}$$

where PY_i^r is the value of gross output in sector $r = 1, ..., \mathrm{R}$ of country $i = 1, ..., \mathrm{N}$, PM_{ij}^{rs} is the value of intermediate uses of this good in country j and sector s, and PC_{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:

$$\mathrm{PY}_i^r = \left[\sum_s \sum_{j \neq i} \mathrm{PM}_{ij}^{rs} + \sum_{j \neq i} \mathrm{PC}_{ij}^r\right] + \left[\sum_s \mathrm{PM}_{ii}^{rs} + \mathrm{PC}_{ii}^r\right], \tag{2}$$

where the second term isolates a component focused on domestic uses only. Define $a_{ij}^{rs} = \frac{\mathrm{PM}_{ij}^{rs}}{\mathrm{PY}_j^s}$ 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

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

Iterating the identity,

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

The first infinite sum in equation (4), denoted with $\text{PY}^r_{i_{\text{DOM}}}$ 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 $\text{PY}^r_{i_{\text{FOR}}}$ 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. $\text{PY}^r_{i_{\text{FOR}}}$ is the main constituting element of HOT.

Definition 1. *Define* HOT^r_i *by*

$$\text{HOT}^r_i = \frac{\text{PY}^r_{i_{\text{FOR}}}}{\text{PY}^r_i}. \tag{5}$$

HOT^r_i 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^r_i *is the typical element of the following Hadamard division*

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

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

2.2 Conventional measures of openness

Conventional measures of openness are based on trade. 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

$$\text{X}^r_i = \frac{\sum_{j \neq i} \text{PC}^r_{ij} + \sum_{j \neq i} \sum_s \text{PM}^{rs}_{ij}}{\text{PVA}^r_i},$$

where the numerator sums the value of total exports from sector r in country i, in final goods with $\sum_{j \neq i} \text{PC}^r_{ij}$ and in intermediate goods with $\sum_{j \neq i} \sum_s \text{PM}^{rs}_{ij}$. The denominator is nominal value added in the sector converted in USD at PPP exchange rates, following Alcalá and Ciccone (2004).

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

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

where $\mathrm{PM}_{ij}^r = \sum_s \mathrm{PM}_{ij}^{rs}$ 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 as

$$\phi_i^r = \sum_{j \neq i} \phi_{ij}^r.$$

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.[9] By applying the Leontief inverse matrix to direct exports, TiVA captures the total value added contained in exports.

It may be 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 is apparent from the fact that HOT applies different Leontief inverses to $\mathbf{PC}$ and to $\mathbf{PC}_{\mathrm{DOM}}$, whereas TiVA applies the same, i.e., decomposes exports.[10] For the same reason HOT can be computed for sectors that do not directly trade abroad, whereas it is harder for TiVA. Second, HOT is naturally bounded between 0 and 1, whereas TiVA needs to be normalized: It is often scaled by total exports to quantify the importance of indirect trade relative to observed direct exports. With this normalization, TiVA can take very high (infinite) values in non traded sectors. This normalization does not account for scale, so that TiVA is sometimes normalized by value added instead. For example Duval et al. (2016) do so in order to evaluate the correlation between value added trade and the international synchronization of GDP.

[9]Omitting the vector $\mathbf{1}$ implies the bilateral version of TiVA, TiVA_{ij}^r

[10]Koopmans, Wang, and Wei (2014) compute the *domestic* value added content of exports, applying $(\mathbf{I} - \mathbf{A}_{\mathrm{DOM}}^m)^{-1}$ to gross exports.

We define the following variants of TiVA,

$$\mathrm{T}_i^r(\mathrm{X}) = \frac{\mathrm{TiVA}_i^r}{\sum_j \mathrm{PC}_{ij}^r + \sum_j \sum_s \mathrm{PM}_{ij}^{rs}}, \ \ \mathrm{T}_i^r(\mathrm{VA}) = \frac{\mathrm{TiVA}_i^r}{\mathrm{PVA}_i^r},$$

In what follows, we compare HOT with the three alternatives just listed, X, ϕ, and T.[11]

2.3 Computing the measures

Define the world input-output matrix $\mathbf{W}$ with typical element PM_{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 PC_{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 PM_{ij}^{rs} and PC_{ij}^r in $\mathbf{W}$ by $\mathrm{PY}_i^r / (\mathrm{PY}_i^r - \mathrm{INV}_i^r)$ 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 $\mathbf{A}_{\mathrm{DOM}}^m$ 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 $\mathbf{PC}_{\mathrm{DOM}}$.

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.[12]

We use the information on yearly value added to compute the relevant measures of sector and aggregate growth, productivity, 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

[11] There are other measures of openness, based for example on observed tariff schedules, or model based. For example, Waugh and Ravikumar (2016) propose a measure of potential trade openness, based on the welfare gains that opening up the economy would create.

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

OECD. The socio-economic indicators from WIOD also report the number of employees at sector level, which we use to compute labor productivity and per capita growth rates. 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 trade openness we consider: HOT, X, ϕ, T(X), and T(VA). The first panel reports unconditional correlations, the second one reports correlations between country averages, and the third panel reports correlations between sector averages.

Several results are of interest. First, HOT, X, and T(VA) are positively correlated, suggesting the three measures tend to imply similar rankings across countries and sectors. Second T(X) captures something quite different from all other variables: Its correlation is essentially zero with all other measures. This reflects the fact that T(X) does not measure openness: It measures the integration of a sector's exports with the supply chain. In contrast, T(VA) correlates positively with the other measures, especially X, presumably because they both embed direct exports and they are both normalized by value added. ϕ also behaves quite differently from the other measures, with correlation coefficients that are mostly below 0.2.

Figures 1 and 2 illustrate these findings graphically. Figure 1 reports the median values of HOT, ϕ, X, T(X), and T(VA) in each country, where all five panels are ranked according to HOT. The ranking of countries according to HOT is standard, 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 T(VA) is by and large similar to HOT but it is quite different according to ϕ and T(X). For example, T(X) takes highest values for Japan and among the lowest in Luxembourg. Figure 2 reports the median values of HOT, ϕ, X, T(X), and T(VA) in each sector, where all five panels are again ranked according to HOT. The ranking of sectors according to HOT is quite different from what is implied by T(X), but resembles the ranking according to X, ϕ, and T(VA). However, the distribution of median values is very different for direct and indirect measures: HOT and 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 3 plots country-level averages of HOT over time for five large economies, along with a world average.[13] 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

[13]Country values are value added weighted averages of sector level HOT. Worldwide HOT is a GDP weighted average of country-level HOT.

crisis. Germany follows an upward trend throughout the period, whereas China peaked in 2006 and has fallen back to early 2000s levels since. In 2014, about one third of the output in the average German sector is affected by foreign shocks. It is closer to a fifth for China. The world average is just shy of 20 percent over the period. India, Japan, and the U.S. are always below world average. The U.S. is by far the least open economy in this sample, although it is following a mild upward trend.

Figures 1 and 2 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 takes a value above 85 million, while X takes a value above 50. As seen on Figure 1, the values for other countries are orders of magnitude smaller. Across sectors, ϕ takes a value around 600 million in Textiles and 1.5 billion in Machinery. X takes a value around 70 in Petrol, more than 30 times the next largest value across sectors on that year (as seen on Figure 2). Obviously these are outliers, which are due to the normalizations inherent to measuring X and ϕ. For the purpose of the figures in this section that are based on 2014 data, these outliers are removed. But dealing with extreme values will be of the essence in regression analysis: It is probably a reason why international data on openness at sector level perform so poorly in regression analyses. We emphasize that HOT displays a well-behaved distribution with no apparent outliers, i.e., the figures showing values for HOT include all observations.

We document these distributional difference in detail in Figure 4, which plots density estimates of HOT, X, ϕ, T(X), and T(VA). Now 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, T(X) and T(VA) also display very large upper tails presumably because of denominators close to zero. 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 5 plots the boxplots (minimum, interquartile range, maximum) of HOT, X, ϕ and both normalizations of T across sectors for all countries. The countries are ranked 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 5. 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 (T(X) and T(VA)). According to conventional measures of openness most sectors are closed, but not according to HOT. This is not surprising: most sectors do not trade across the border directly, but most do trade across the border indirectly.

Figure 6 plots the distributions of HOT, X, ϕ, T(X), and 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. For example Metals, Electric Equipment, and Computers are among the most open sectors according to HOT. And 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.

The lower panels of Figure 6 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. T(X) is particularly striking, as it takes lowest values for manufacturing sectors, and high values for a few so-called non traded sectors like Real Estate.[14] 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.

[14]Similar results are documented in Johnson and Noguera (2012).

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 the various measures of openness. Finally we examine the correlations between the simulated measures of openness and the simulated responses 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.[15] Cost minimization 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 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

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

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 we assume a structure for transport costs 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 $\mathrm{P}_i\,\mathrm{C}_i =$

[15] 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 understand an empirical measure of openness.

$\sum_r \mathrm{W}_i^r \, \mathrm{H}_i^r + \sum_r \mathrm{R}_i^r \, \mathrm{K}_i^r$, where

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

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

ρ is the elasticity of substitution between final goods, R_i^r denotes the rental rate of capital, and W_i^r denotes the wage rate in sector r of country i. Labor supply is given by

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

And expenditure shares in the final good are given by

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

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

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

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

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

The equilibrium response of the economy to the technology shocks Z_i^r can be characterized in deviations from a steady state. In particular the response of real output can be expressed in matrix algebra making use of the following definitions of steady state ratios.

Definition 2.

> $\mathbf{A}^m$ *is the matrix with typical element the direct requirement coefficient* $a_{ij}^{rs} = \frac{\mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}}{\mathrm{PY}_j^s} = (1 - \eta^s) \frac{\mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}}{\mathrm{P}_j^s \, \mathrm{M}_j^s}$ *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* $ac_{ij}^r = \frac{\mathrm{P}_{ij}^r \, \mathrm{C}_{ij}^r}{\mathrm{P}_j \, \mathrm{C}_j}$ *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* $b_{ij}^{rs} = \frac{(1-\eta^s)\,\mathrm{PY}_j^s\,\xi_{ij}^{rs}}{\mathrm{PY}_i^r} = \frac{\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs}}{\mathrm{PY}_i^r}$ *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* $bc_{ij}^r = \frac{\pi_{ij}^r\,\mathrm{P}_j\,\mathrm{C}_j}{\mathrm{PY}_i^r} = \frac{\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r}{\mathrm{PY}_i^r}$ *the share of output in source sector* (i, r) *used as final consumption in country* j.

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

In Appendix A we review the key steps followed by Huo et al. (2021) to show that in deviations from the steady state (denoted by ln), the equilibrium response of output is given by

$$\ln \mathbf{Y}_t = \boldsymbol{\Lambda}^{-1} \ln \mathbf{Z}_t \tag{7}$$

where $\boldsymbol{\Lambda}$ is derived in Appendix A as a function of the steady state value matrices introduced in Definition 2. 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.[16] $\boldsymbol{\Lambda}^{-1}$ 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:

$$\ln \mathbf{V}_t = \frac{1+\psi}{\psi} \ln \mathbf{H}_t, \tag{8}$$

Using the equilibrium value for labor given in (A.14), the response of labor productivity $\mathbf{VH}$ is straightforward to obtain from equation (8):

$$\ln \mathbf{VH}_t = \frac{1}{1+\psi}\Big[\ln \mathbf{PY}_t - \Big(\left(\mathbf{A}^c\right)^\top \otimes \mathbf{1}\Big) \ln \mathbf{P}_t\Big].$$

This implies that the responses of labor productivity and nominal output are proportional, up to the response of prices $\ln \mathbf{P}_t$. Abstracting from prices for the moment, this means that the response of labor productivity to foreign shocks is proportional to $\ln \mathbf{PY}_{t\mathrm{FOR}}$, the response of nominal output to foreign shocks. In other words, abstracting from $\ln \mathbf{P}_t$ the response of labor productivity to foreign shocks is well measured by HOT.[17]

We see this clearly when expressing HOT in deviations from its steady state. The

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

[17] This proportionality would continue to prevail in a model with capital accumulation, since it would continue to capture impact responses to shocks.

steady state value of HOT is given by

$$\begin{aligned}\mathrm{HOT}_i^r &= 1 - \frac{\mathrm{PY}^r_{i_{\mathrm{DOM}}}}{\mathrm{PY}_i^r} \\ &= 1 - \frac{\sum_s \lambda_{ii}^{rs} bc_{ii}^r}{\sum_j \sum_s \lambda_{ij}^{rs} bc_{ij}^r},\end{aligned}$$

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

$$\ln \mathbf{HOT}_t = \mathbf{H_1} \odot \left(\ln \mathbf{PY}_t - \ln \mathbf{PY}_{t_{\mathrm{DOM}}} \right), \tag{9}$$

where $\frac{1-\mathrm{HOT}_i^r}{\mathrm{HOT}_i^r}$ is a typical element of $\mathbf{H_1}$ and $\odot$ is the Hadamard product. In deviations from the steady state $\ln \mathbf{HOT}_t$ is proportional to the response of nominal output to foreign shocks given by $\ln \mathbf{PY}_t - \ln \mathbf{PY}_{t_{\mathrm{DOM}}}$. This in turn is proportional to the response of labor productivity $\mathbf{VH}$ to foreign shocks, as long as we abstract from price responses.

Of course in general equilibrium prices respond to supply shocks: Intuitively, their response depends on the two elasticities of substitution, between final and between intermediate goods, ρ and ϵ. For strong substitutes the response of prices to supply shocks is muted. We expect therefore that HOT correlates strongly with the response of labor productivity to foreign shocks for $\rho, \epsilon > 1$. The correlation should be weaker for low substitutability. In addition with high substitutes supply shocks affect downstream demand positively since the responses in quantities are larger than the responses in prices. Then, supply shocks can travel both down- and up-stream, like the "demand chain" discussed by Guerrieri et al. (2021) in the context of COVID-19.[18]

3.2 Simulations

We exploit the model to simulate the responses to shocks of all variables of interest. Our objective is to gauge which measure(s) of openness best replicate the simulated responses of labor productivity to a combination of domestic and foreign shocks. The responses of HOT ($\ln \mathbf{HOT}_t$) and of value added per worker ($\ln \mathbf{VH}_t$) 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.[19] Consider first total gross exports as a fraction of value added. In terms of the model, at the steady state we

[18] Under unitary elasticities supply shocks propagate downstream only. See for instance Acemoglu et al. (2016) or Baqaee and Farhi (2019b).

[19] We do not include T(X) in the analysis given its low correlation with other measures.

have:

$$\mathrm{X}_i^r = \sum_{j\neq i} \frac{ac_{ij}^r \,\mathrm{PC}_j}{\eta^r\,\mathrm{Y}_i^r} + \sum_s \sum_{j\neq i} \frac{\mathrm{PM}_{ij}^{rs}}{\eta^r PY_i^r}$$
$$= \sum_{j\neq i} \frac{bc_{ij}^r}{\eta^r} + \sum_s \sum_{j\neq i} \frac{b_{ij}^{rs}}{\eta^r},$$

In deviations from the steady state, this implies

$$\ln \mathrm{X}_{i,t}^r = \frac{1}{\mathrm{X}_i^r}\left[\sum_{j\neq i} \frac{ac_{ij}^r \,\mathrm{P}_j\,\mathrm{C}_j}{\eta^r\,\mathrm{P}_i^r\,\mathrm{Y}_i^r}(\ln \mathrm{PC}_{ij,t}^r - \ln \mathrm{PY}_{i,t}^r) + \sum_s \sum_{j\neq i} \frac{\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs}}{\eta^r\,\mathrm{P}_i^r\,\mathrm{Y}_i^r}(\ln \mathrm{PM}_{ij,t}^{rs} - \ln \mathrm{PY}_{i,t}^r)\right]$$
$$= \frac{1}{\eta^r}\frac{\sum_{j\neq i} bc_{ij}^r}{\mathrm{X}_i^r} \ln \mathrm{PC}_{ij,t}^r + \frac{1}{\eta^r}\frac{\sum_s \sum_{j\neq i} b_{ij}^{rs}}{\mathrm{X}_i^r} \ln \mathrm{PM}_{ij,t}^{rs} - \ln \mathrm{PY}_{i,t}^r\,.$$

In Appendix B we derive expressions for $\ln \mathrm{PM}_{ij,t}^{rs}$, $\ln \mathrm{PC}_{ij,t}^r$, and $\ln \mathrm{PY}_{i,t}^r$ to substitute them into the definition of gross exports. We 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

$$\phi_{ij}^r = \left(\frac{\Phi_{ij}^r}{\Phi_{ii}^r} \times \frac{\Phi_{ji}^r}{\Phi_{jj}^r}\right)^{\frac{1}{2}}$$
$$= \left(\frac{\sum_s b_{ij}^{rs} + bc_{ij}^r}{\sum_s b_{ii}^{rs} + bc_{ii}^r} \times \frac{\sum_s b_{ji}^{rs} + bc_{ji}^r}{\sum_s b_{jj}^{rs} + bc_{jj}^r}\right)^{\frac{1}{2}},$$

where $\Phi_{ij}^r = \sum_s \frac{\mathrm{PM}_{ij}^{rs}}{\mathrm{PY}_i^r} + \frac{\mathrm{PC}_{ij}^r}{\mathrm{PY}_i^r}$ and we have normalized each term in the ratio by nominal output. In deviations from the steady state

$$\ln \phi_{ij,t}^r = \frac{1}{2}(\phi_{ij}^r)^{-\frac{1}{2}}\Bigg(\ln \Phi_{ij,t}^r - \ln \Phi_{ii,t}^r + \ln \Phi_{ji,t}^r - \ln \Phi_{jj,t}^r\Bigg).$$

Aggregating to the country level

$$\ln \phi_{i,t}^r = \sum_{j\neq i} \frac{\phi_{ij}^r}{\phi_i^r} \ln \phi_{ij,t}^r$$
$$= \frac{1}{2}\sum_{j\neq i} \frac{(\phi_{ij}^r)^{\frac{1}{2}}}{\phi_i^r}\Bigg(\ln \Phi_{ij,t}^r - \ln \Phi_{ii,t}^r + \ln \Phi_{ji,t}^r - \ln \Phi_{jj,t}^r\Bigg)$$

Each element $\Phi_{ij,t}^r$ of $\ln \phi_{i,t}^r$ depends on $\ln \mathrm{PM}_{ij,t}^{rs}$, $\ln \mathrm{PC}_{ij,t}^r$, and $\ln \mathrm{PY}_{i,t}^r$ whose expressions are derived in Appendix B. We use these expressions to spell out the corresponding reduced form expression for $\ln \phi_{i,t}^r$ 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

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

so that in deviations from the steady state

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

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

We simulate the responses of value added per worker, HOT, X, ϕ, and T(VA) to a combination of domestic and foreign shocks: Each country in the model economy (except the US) is subjected to a positive aggregate domestic and a positive aggregate US supply shock. All shocks are calibrated to the empirical standard deviation of aggregate gross output. We collect the responses to both shocks of all five variables of interest and perform regression analysis on the basis of these simulated data that comprise a maximum of 50 $\times$ 42 observations. We present the results in Tables 2 and 3.

Table 2 first presents the simulated regressions between labor productivity and HOT; We then include the three other simulated openness measures as potentially relevant controls. The regressions are performed for different values of the elasticities ρ and ϵ. Theoretically we expect HOT to best capture the response of productivity to shocks for high substitutability in intermediate and final goods.[20] The simulation results are clear from Table 2: The responses of labor productivity and of HOT correlate positively and significantly for all parameter combinations. Including controls for X, ϕ, or T(VA) does not alter the result and 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 when both elasticities are below one.

Table 3 completes the evidence reporting the correlation between simulated labor productivity and each of the three measures of openness taken one at a time. It shows that in the model none of the three alternatives to HOT -X, ϕ, or T(VA)- displays a systematic positive and significant correlation with labor productivity. If anything most coefficients are negative and significant. HOT is the only variable that captures well the exposure of labor productivity to foreign shocks. That happens because HOT reflects

[20]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.

the effect of foreign shocks on output (and not exports like X or 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 shocks on labor productivity. 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: productivity, growth, and synchronization. We examine these correlations in an international sector-level database with coverage that we believe is unprecedented.

4.1 Openness and Productivity

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. Productivity is value added per employee, measured in real PPP USD. Panel tests reject the null of non-stationarity in the cross section.[21] We estimate:

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

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 institutional quality or capital intensity. They also control for any permanent differences in productivity specific to a given sector in a specific country, e.g., agriculture in a developing country. To assuage non-stationarity concerns, we also perform the estimation in first differences.

Table 4 presents the results.[22] HOT correlates significantly and positively with labor productivity at sector level, whether the other measures are included or not. In fact, HOT is the only significant correlate of labor productivity: the coefficient estimates on X, ϕ, and T(VA) are either insignificant or have the wrong sign. When we classify the 50

[21] We implemented three types of panel unit-root tests: Fisher (also known as Phillips-Perron), Im-Pesaran-Shin, and Levin-Lin-Chu tests, with one lag, demeaned series, and with or without time trends. Unit roots were rejected in all cases.

[22] 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 T(VA) in the main text, reasoning their distributions do not suggest the presence of extreme values. We did verify that winsorizing HOT and T(VA) does not alter substantially our results.

sectors in WIOD into three broad categories, Agriculture, Manufacturing, and Services, HOT correlates with productivity in all three, albeit most weakly in Agriculture. On the other hand, productivity 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 labor productivity 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. In theory open sectors are exposed to foreign technology shocks, which increases the marginal product of capital, stimulate investment and growth. The literature addressing the question empirically is extensive and a thorough review is not in order here. Most famously Frankel and Romer (1999) establish growth can be a consequence of openness at country level, using geographic and gravity variables as instruments for openness. These important results have been subjected to enormous scrutiny since and it is fair to say the conclusions are not uncontroversial (see for instance Rodríguez and Rodrik, 2000). Asking the growth question in a panel of sectors across countries is even more difficult, maybe because until Rodrik (2013) the basic growth estimation appeared to be invalid in a cross-sector, cross-country panel.

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. Rodrik (2013) includes sector effects only, arguing this constitutes a test of unconditional convergence. We augment the specification with country effects as well, a test for conditional convergence. The data are winsorized as described in the previous section. Specifically, we estimate

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

where ς denotes the period over which growth rates are computed and $\mathrm{VH}^r_{i,\varsigma}$ is value added per capita at the beginning of period ς. The specification can be augmented with period effects when $\varsigma \geq 2$.

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). As in Rodrik (2013), there is convergence as $\beta_0 < 0$ everywhere.[23] HOT correlates positively and significantly with growth, whether the other measures are included or not. The correlation is positive

[23] Interestingly convergence holds beyond manufacturing sectors.

and significant in manufacturing sectors. In contrast, X, ϕ, and T(VA) display no significant correlation with growth, either in the aggregate or across all three broad categories.

The lower panel presents estimates of equation (10) using instrumental variables. We introduce an instrument for the cross-section of HOT that makes us of its network properties. By definition

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

A natural way to instrument HOT in cross-section is to hold the coefficients λ_{ij}^{rs} in the Leontief inverse at their steady state values, given by the time average of the elements in WIOD. By construction, the elements of $\mathbf{A}^m$ at the steady state are invariant to shocks. Of course final demand PC_{ij}^s does respond to shocks. So we introduce an "adjacency vector" for final demand with element $\widetilde{\mathrm{PC}}_{ij}^s = 1$ if $\mathrm{PC}_{ij}^s \neq 0$, by analogy with an adjacency matrix where all non zero entries are set to unity. The vector captures *whether* a link exists with final demand, a cross-section that barely changes over time.[24] The resulting instrument for HOT is defined as

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

where $\widetilde{\mathrm{PC}}_{ij,0}^s$ 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 $\mathrm{PC}_{ij,0}^s$ are replaced with 1.

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.

[24] The correlation between "adjacency vectors" measured in 2000 and 2014 is 0.985.

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.[25]

We now discuss the measurement strategy followed to extend the estimations in sections 4.1 and 4.2 to a bilateral context. In theory the response of labor productivity to foreign shocks is (close to) proportional to HOT. So the contribution of foreign shocks to co-movements should be closely related to a measure of co-movements in HOT. We introduce a bilateral measure of HOT given by

$$\text{HOT}_{ij}^{rs} = \text{HOT}_i^r \times \text{HOT}_j^s \,.$$

By definition HOT_{ij}^{rs} reflects how much two sectors are open to each other and how much they are open to foreign shocks happening in third countries, at any order through the supply chain.[26]

Measuring cycle synchronization over time is not straightforward. Two approaches stand out in the literature. The first one computes an absolute difference in growth rates, as in

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

where $g_{i,t}^r$ denotes the growth rate in per capita income in country i, sector r at time t. The measure was popularized among others by Giannone et al. (2010) and Kalemli-Özcan et al. (2013). The second measure computes the quasi correlation between sector growth rates, given by

$$\text{SYNC2}_{ij,t}^{rs} = \frac{(g_{i,t}^r - \bar{g}_i^r) \times (g_{j,t}^s - \bar{g}_j^s)}{\sigma_i^r \sigma_j^s},$$

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). In what follows we present results using both SYNC1 and SYNC2.

It is straightforward to extend the other three measures of openness to a bilateral

[25]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.

[26]The measure conflates bilateral and multilateral sources of co-movements. This is different from Huo et al (2021), who separate the two sources of co-movements when they quantify the role of propagation for co-movements.

context. Bilateral trade data are typically only available for intermediate goods. 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:

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

We explore the correlation between synchronization and openness by estimating

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

where SYNC is either SYNC1 (in Table 6) or SYNC2 (in Table C.5). Following the literature, measures of openness enter equation (11) in logarithms. Both tables present estimates of β_1 when $\mathrm{HOT}_{ij,t}^{rs}$ is the sole regressor, ask whether the estimate changes when all measures of openness are included, and then report the estimates of β_1 for the six bilateral correlations between agriculture, manufacturing, and services. The results are unambiguous: $\mathrm{HOT}_{ij,t}^{rs}$ and sector-level co-movements are significantly positively correlated whether or not other measures of openness are included and irrespective of the measure used for SYNC. Estimates of β_1 are positive for most pairs of sectors, and particularly for those involving services. The significance of coefficient estimates is somewhat more diffuse in Table C.5, presumably because the quasi-correlation coefficient is measured with error especially at sector level. But even there the correlation between SYNC and $\mathrm{HOT}_{ij,t}^{rs}$ is always positive and significant when all sectors are included, and coefficient estimates are positive, significant, and high when services are involved. The same is not true for any of the other measures of openness. This is probably the reason why such sector-level cross-country bilateral regressions have not been successfully performed yet.

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 and labor productivity 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 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 observed labor productivity, growth, and synchronization. None of the other standard measure of openness does.

References

Acemoglu, D., Akcigit, U., and Kerr, W. (2016). Networks and the Macroeconomy: An Empirical Exploration, volume 30, chapter 4, pages 276 – 335. University of Chicago Press.

Alcalá, F. and Ciccone, A. (2004). Trade and Productivity. The Quarterly Journal of Economics, 119(2):613–646.

Alfaro, L., Antràs, P., Chor, D., and Conconi, P. (2019). Internalizing Global Value Chains: A Firm-Level Analysis. Journal of Political Economy, 127(2):508–559.

Amiti, M. and Konings, J. (2007). Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia. American Economic Review, 97(5):1611–1638.

Antràs, P. and Chor, D. (2013). Organizing the Global Value Chain. Econometrica, 81(6):2127–2204.

Antràs, P. and Chor, D. (2018). On the Measurement of Upstreamness and Downstreamness in Global Value Chains. In Ing, L. Y. and Yu, M., editors, World Trade Evolution: Growth, Productivity and Employment, chapter 5. Routledge.

Atalay, E., Hortaçsu, A., Li, M. J., and Syverson, C. (2019). How Wide Is the Firm Border? The Quarterly Journal of Economics, 134(4):1845–1882.

Baldwin, R., Forslid, R., Martin, P., and Robert-Nicoud, F. (2003). The Core-Periphery Model: Key Features and Effects. In The Monopolistic Competition Revolution in Retrospect, pages 213–235. Cambridge University Press.

Baqaee, D. and Farhi, E. (2019a). Networks, barriers, and trade. Working Paper 26108, National Bureau of Economic Research.

Baqaee, D. R. and Farhi, E. (2019b). Productivity and Misallocation in General Equilibrium*. The Quarterly Journal of Economics, 135(1):105–163.

Bems, R. and Johnson, R. C. (2017). Demand for Value Added and Value-Added Exchange Rates. American Economic Journal: Macroeconomics, 9(4):45–90.

Bems, R. and Kikkawa, A. K. (2019). Measuring trade in value added with Firm-Level Data. Working Paper Research 378, National Bank of Belgium.

Bernard, A. B. and Jensen, J. B. (1995). Exporters, Jobs, and Wages in U.S. Manufacturing: 1976-1987. Brookings Papers on Economic Activity, 26(1995 Microeconomics):67–119.

Bernard, A. B. and Jensen, J. B. (1999). Exceptional exporter performance: cause, effect, or both? Journal of International Economics, 47(1):1–25.

Bernard, A. B. and Jensen, J. B. (2004). Why Some Firms Export. The Review of Economics and Statistics, 86(2):561–569.

Bernard, A. B., Moxnes, A., and Ulltveit-Moe, K. H. (2018). Two-Sided Heterogeneity and Trade. The Review of Economics and Statistics, 100(3):424–439.

Bøler, E. A., Moxnes, A., and Ulltveit-Moe, K. H. (2015). R&D, International Sourcing, and the Joint Impact on Firm Performance. American Economic Review, 105(12):3704–3739.

Christen, E. and François, J. (2017). Modes of Supply for U.S. Exports of Services. The World Economy, 40(3):517–531.

Correia, S. (2017). REGHDFE: Stata module for linear and instrumental-variable/GMM regression absorbing multiple levels of fixed effects. Statistical Software Components s457874, Boston College Department of Economics.

De Loecker, J. and Van Biesebroeck, J. (2018). Effect of International Competition on Firm Productivity and Market Power. In Grifell-Tatjé, E., Lovell, C., and Sickles, R., editors, The Oxford Handbook of Productivity Analysis. Oxford University Press.

di Giovanni, J. and Levchenko, A. A. (2010). Putting the Parts Together: Trade, Vertical Linkages, and Business Cycle Comovement. American Economic Journal: Macroeconomics, 2(2):95–124.

di Giovanni, J., Levchenko, A. A., and Mejean, I. (2017). Large Firms and International Business Cycle Comovement. American Economic Review, 107(5):598–602.

di Giovanni, J., Levchenko, A. A., and Mejean, I. (2018). The Micro Origins of International Business Cycle Comovement. American Economic Review, 108(1):82–108.

Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., and de Vries, G. (2013). The Construction of World Input-Output Tables in the WIOD Project. Economic Systems Research, 25:71–98.

Duval, R., Li, N., Saraf, R., and Seneviratne, D. (2016). Value-Added Trade and Business Cycle Synchronization. Journal of International Economics, 99:251 – 262.

Eaton, J. and Kortum, S. (2018). Trade in Goods and Trade in Services. In Ing, L. Y. and Yu, M., editors, World Trade Evolution: Growth, Productivity and Employment, chapter 4, pages 82–125. Routledge, London.

Eckert, F., Ganapati, S., and Walsh, C. (2019). Skilled Tradable Services: The Transformation of U.S. High-Skill Labor Markets. Working Papers 25, Federal Reserve Bank of Minneapolis, Opportunity and Inclusive Growth Institute.

Egger, P. H., Francois, J., and Nelson, D. R. (2017). The Role of Goods-Trade Networks for Services-Trade Volume. The World Economy, 40(3):532–543.

Fally, T. and Hillberry, R. (2018). A Coasian Model of International Production Chains. Journal of International Economics, 114:299 – 315.

Frankel, J. A. and Romer, D. H. (1999). Does Trade Cause Growth? American Economic Review, 89(3):379–399.

Frankel, J. A. and Rose, A. K. (1998). The Endogenity of the Optimum Currency Area Criteria. The Economic Journal, 108(449):1009–1025.

Gervais, A. and Jensen, J. B. (2019). The tradability of Services: Geographic Concentration and Trade Costs. Journal of International Economics, 118:331 – 350.

Giannone, D., Lenza, M., and Reichlin, L. (2010). Business Cycles in the Euro Area. In Alesina, A. and Giavazzi, F., editors, Europe and the Euro, pages 141–167. University of Chicago Press.

Guerrieri, V., Lorenzoni, G., Straub, L., and Werning, I. (2021). Macroeconomic implications of covid-19: Can negative supply shocks cause demand shortages? Forthcoming American Economic Review.

Halpern, L., Koren, M., and Szeidl, A. (2015). Imported Inputs and Productivity. American Economic Review, 105(12):3660–3703.

Head, K. and Mayer, T. (2004). The Empirics of Agglomeration and Trade. In Handbook of Regional and Urban Economics, chapter 59. North-Holland.

Huo, Z., Levchenko, A. A., and Pandalai-Nayar, N. (2020). Utilization-Adjusted TFP Across Countries: Measurement and Implications for International Comovement. Working Paper 26803, National Bureau of Economic Research.

Huo, Z., Levchenko, A. A., and Pandalai-Nayar, N. (2021). International Comovement in the Global Production Network. Working Paper 25978, National Bureau of Economic Research.

Jensen, J. and Kletzer, L. (2005). Tradable Services: Understanding the Scope and Impact of Services Outsourcing. Brookings Trade Forum.

Johnson, R. C. (2014). Trade in Intermediate Inputs and Business Cycle Comovement. American Economic Journal: Macroeconomics, 6(4).

Johnson, R. C. and Noguera, G. (2012). Accounting for intermediates: Production Sharing and Trade in Value Added. Journal of International Economics, 86(2):224 – 236.

Kalemli-Özcan, Ş., Papaioannou, E., and Peydró, J.-L. (2013). Financial Regulation, Financial Globalization, and the Synchronization of Economic Activity. The Journal of Finance, 68(3):1179–1228.

Koopman, R., Wang, Z., and Wei, S.-J. (2014). Tracing Value-Added and Double Counting in Gross Exports. American Economic Review, 104(2):459–94.

Rodríguez, F. and Rodrik, D. (2000). Trade Policy and Economic Growth: A Skeptic's Guide to the Cross-National Evidence. NBER Macroeconomics Annual, 15:261–325.

Rodrik, D. (2013). Unconditional Convergence in Manufacturing. The Quarterly Journal of Economics, pages 165–204.

Timmer, M., Los, B., Stehrer, R., and de Vries, G. (2016). An Anatomy of the Global Trade Slowdown based on the WIOD 2016 Release. GGDC Research Memorandum GD-162, Groningen Growth and Development Centre, University of Groningen.

Tintelnot, F., Kikkawa, A. K., Mogstad, M., and Dhyne, E. (2018). Trade and Domestic Production Networks. Working Paper 25120, National Bureau of Economic Research.

Topalova, P. and Khandelwal, A. (2011). Trade liberalization and firm productivity: The case of india. The Review of Economics and Statistics, 93(3):995–1009.

Waugh, M. E. and Ravikumar, B. (2016). Measuring Openness to Trade. Journal of Economic Dynamics and Control, 72:29 – 41. Trade and macroeconomics: new approaches to enduring puzzles.

Table 1: Correlations

	HOT^r_i	ϕ^r_i	X^r_i	$T^r_i(X)$	$T^r_i(VA)$
			Entire sample		
HOT^r_i	1				
ϕ^r_i	0.061	1			
X^r_i	0.388	0.036	1		
$T^r_i(X)$	-0.013	-0.003	-0.003	1	
$T^r_i(VA)$	0.325	0.030	0.677	-0.004	1
			By country		
HOT^r_i	1				
ϕ^r_i	-0.045	1			
X^r_i	0.388	0.031	1		
$T^r_i(X)$	-0.048	0.410	-0.023	1	
$T^r_i(VA)$	0.271	0.019	0.971	-0.020	1
			By sector		
HOT^r_i	1				
ϕ^r_i	0.200	1			
X^r_i	0.674	0.148	1		
$T^r_i(X)$	-0.053	-0.007	-0.028	1	
$T^r_i(VA)$	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 Productivity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\ln HOT^r_{i,t}$	0.051***	0.058***	0.047***	0.016***	0.056***	0.064***	0.009***	0.005***
	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.000)	(0.000)
$\ln X^r_{i,t}$		-0.171***		0.272***		-0.072***		-0.005
		(0.017)		(0.017)		(0.017)		(0.008)
$\ln T^r_{i,t}(VA)$		0.092***		-0.723***		0.141***		-0.064***
		(0.018)		(0.011)		(0.011)		(0.011)
$\ln \phi^r_{i,t}$		-0.012***		-0.011***		-0.002		0.007***
		(0.001)		(0.001)		(0.001)		(0.000)
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 the log deviation of labour productivity from the steady state $\ln\left(\frac{V^r_{i,t}}{H^r_{i,t}}\right)$. All the regressors are defined in the text. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Simulations: Other measures of openness and Productivity

	(1)	(2)	(3)	(4)
$\ln \mathrm{X}^r_{i,t}$	-0.356***	-0.607***	-0.255***	-0.121***
	(0.013)	(0.022)	(0.013)	(0.004)
Obs.	2,000	2,000	2,000	2,000
$\ln \mathrm{T}^r_{i,t}(\mathrm{VA})$	-0.077***	-0.665***	0.099***	-0.141***
	(0.016)	(0.007)	(0.010)	(0.004)
Obs.	2,018	2,018	2,018	2,018
$\ln \phi^r_{i,t}$	-0.007***	-0.005***	-0.002	0.006***
	(0.001)	(0.002)	(0.001)	(0.000)
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 the log deviation of labour productivity from the steady state $\ln\left(\frac{\mathrm{V}^r_{i,t}}{\mathrm{H}^r_{i,t}}\right)$. All the regressors are defined in the text. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Productivity Estimations

	All sectors (1)	All sectors (2)	Agr (3)	Mfg (4)	Ser (5)
		Fixed Effects Estimations			
HOT_i^r	0.382***	0.548***	0.529**	0.610***	0.481***
	(0.060)	(0.076)	(0.256)	(0.104)	(0.140)
X_i^r		-0.103***	-0.109	-0.032	-0.202***
		(0.031)	(0.139)	(0.038)	(0.057)
ϕ_i^r		0.039	-0.145	0.018	0.047
		(0.029)	(0.162)	(0.035)	(0.052)
$T_i^r(VA)$		-0.002	-0.019	0.022	-0.114
		(0.041)	(0.073)	(0.044)	(0.100)
Obs.	30,311	30,311	1,830	11,699	13,743
		First Difference Estimations			
HOT_i^r	0.084**	0.450***	0.281**	0.464***	0.672**
	(0.041)	(0.108)	(0.148)	(0.093)	(0.270)
X_i^r		-0.266***	-0.153	-0.231***	-0.388***
		(0.053)	(0.098)	(0.044)	(0.102)
ϕ_i^r		0.020*	-0.055	0.008	0.046***
		(0.012)	(0.039)	(0.017)	(0.017)
$T_i^r(VA)$		-0.159	0.026	-0.127	-0.349
		(0.102)	(0.037)	(0.096)	(0.267)
Obs.	28,272	28,272	1,708	10,909	12,822

Note: The dependent variable is productivity measured as the natural logarithm of real Value Added per employee in sector r of country i. Value Added is in real PPP USD. All regressions include country × sector fixed effects. Robust standard errors in parentheses, clustered at country-sector level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Growth Estimations

	All sectors (1)	All sectors (2)	Agr (3)	Mfg (4)	Ser (5)
			OLS estimations		
Initial V.A.	-0.036***	-0.036***	-0.029***	-0.033***	-0.043***
	(0.002)	(0.002)	(0.008)	(0.003)	(0.003)
HOT_i^r	0.020***	0.027***	0.037	0.063***	-0.005
	(0.006)	(0.009)	(0.041)	(0.015)	(0.017)
X_i^r		-0.005	-0.007	-0.017***	0.006
		(0.004)	(0.016)	(0.006)	(0.008)
ϕ_i^r		<0.001	<0.001	<0.001	<0.001
		(<0.001)	(0.002)	(<0.001)	(<0.001)
T_i^r(VA)		0.005**	-0.010	0.005	0.016*
		(0.002)	(0.009)	(0.004)	(0.009)
Obs.	2019	2019	122	779	916
			IV estimations		
Initial V.A.	-0.036***		-0.037***	-0.033***	-0.044***
	(0.002)		(0.006)	(0.003)	(0.003)
HOT_i^r	0.096***		0.116*	0.069***	0.114***
	(0.015)		(0.062)	(0.023)	(0.030)
Anderson-Rubin:					
Statistic	37.44		4.298	7.530	15.48
p-value	<0.001		0.038	0.006	<0.001
Confidence Sets	[0.067, 0.125]		[0.010, $+\infty$]	[0.024, 0.111]	[0.059, 0.179]
Obs.	2019		122	779	916

Note: The dependent variable is the natural logarithm of growth in Value Added per employee in country i sector r. Initial V.A. is the initial value added per employee. Value Added is in real 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. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Synchronization (Absolute Difference)

	All sectors (1)	All sectors (2)	Agr-Agr (3)	Agr-Mfg (4)	Agr-Ser (5)	Mfg-Mfg (6)	Mfg-Ser (7)	Ser-Ser (8)
HOT_{ij}^{rs}	0.263***	0.326***	-0.3418	0.390***	0.224***	0.341***	0.330***	0.220***
	(0.014)	(0.016)	(0.290)	(0.078)	(0.073)	(0.042)	(0.027)	(0.025)
X_{ij}^{rs}		-0.111***	-0.383***	-0.549***	-0.484***	0.002***	-0.0004***	-0.001***
		(0.008)	(0.098)	(0.037)	(0.031)	(0.026)	(0.015)	(0.013)
ϕ_{ij}^{rs}		0.026***	0.028	0.157***	-0.006	0.204***	0.028*	-0.237***
		(0.008)	(0.093)	(0.032)	(0.024)	(0.024)	(0.014)	(0.012)
$\text{T}_{ij}^{rs}(\text{VA})$		0.008	0.680***	0.238***	0.484***	-0.231***	-0.131***	0.082***
		(0.009)	(0.160)	(0.043)	(0.041)	(0.022)	(0.015)	(0.013)
Obs.	26,071,229	22,546,820	68,723	982,452	1,023,281	3,671,535	8,029,573	4,555,345

Note: The dependent variable is $-|\log(\frac{VA_i^r}{N_i^r}) - \log(\frac{VA_j^s}{N_j^s})|$. Value Added is in real PPP USD. The regressions are performed with reghdfe in STATA, which allows for multiple level fixed effects (see Correia, 2017). Robust standard errors in parentheses, clustered at country-sector pair level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All coefficients and standard errors have been multiplied by 100 for legibility.

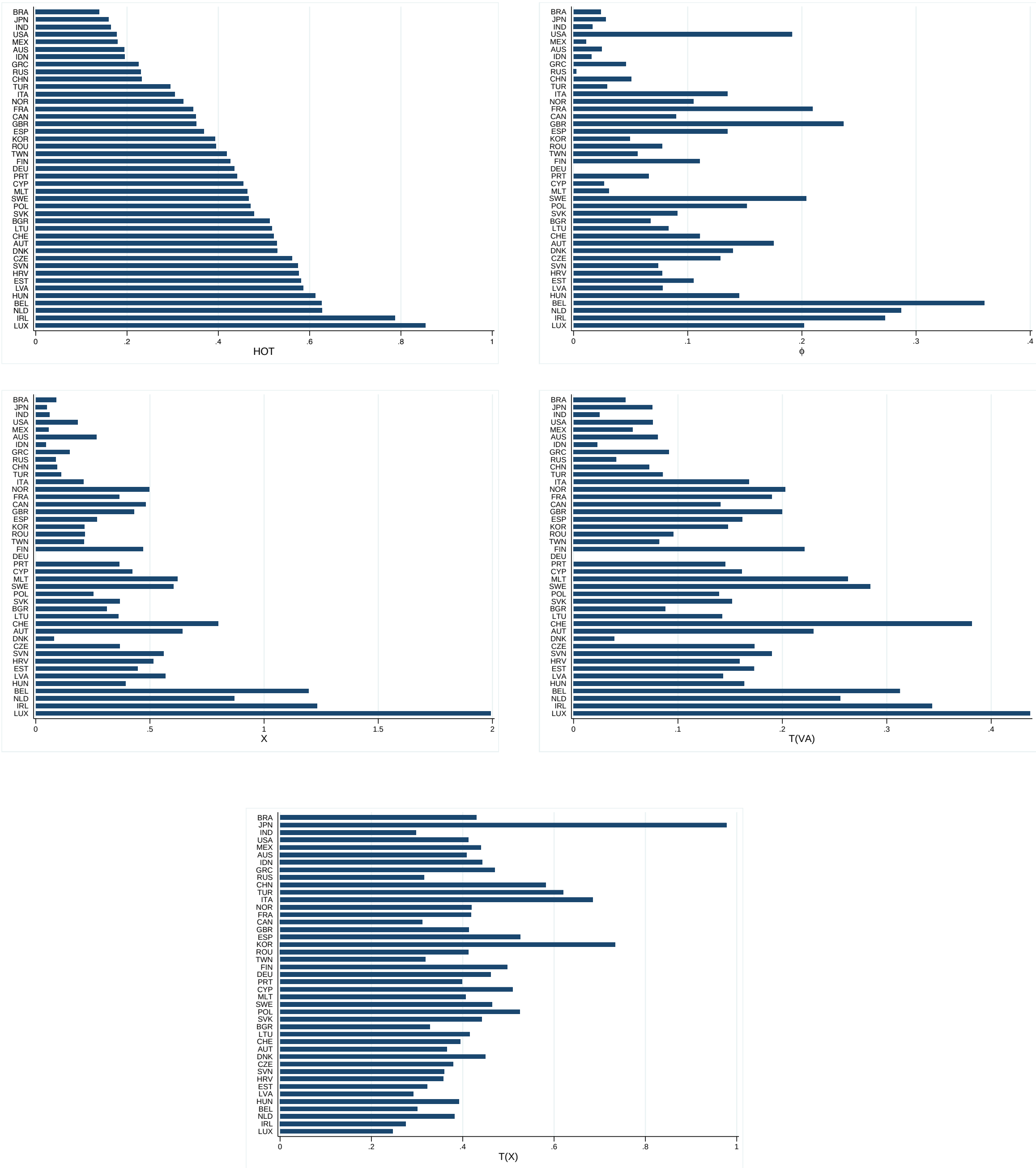

Figure 1: Median sector values of HOT_i^r, ϕ_i^r, X_i^r, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_i^r(\mathrm{X})$ by country in 2014.

Figure 2: 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.

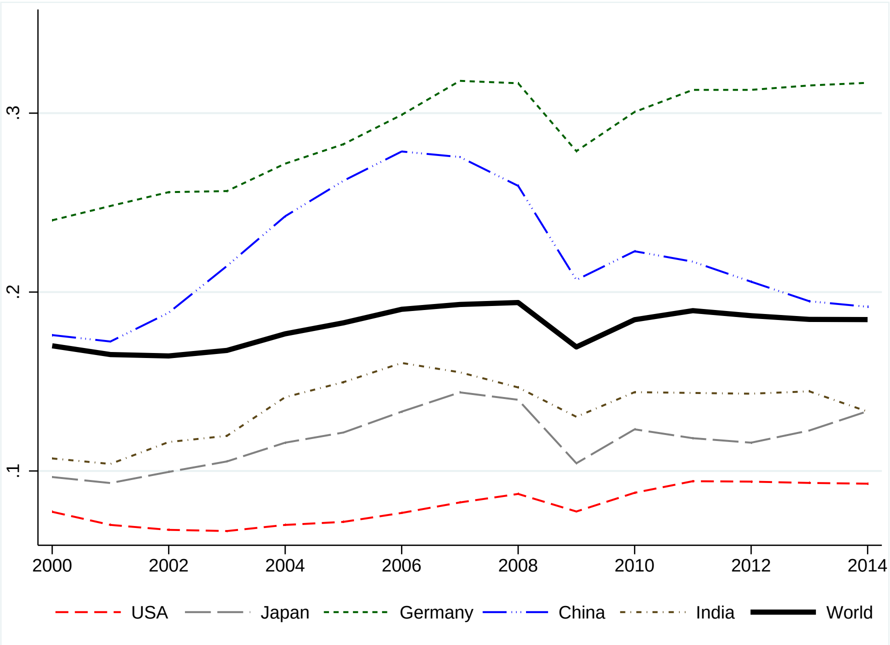

Figure 3: HOT is depicted over time for five countries and the World. Country values are value added weighted averages of sector level HOT_i^r. Worldwide HOT is a GDP weighted average of country-level HOT. Value added is converted in USD at PPP exchange rate.

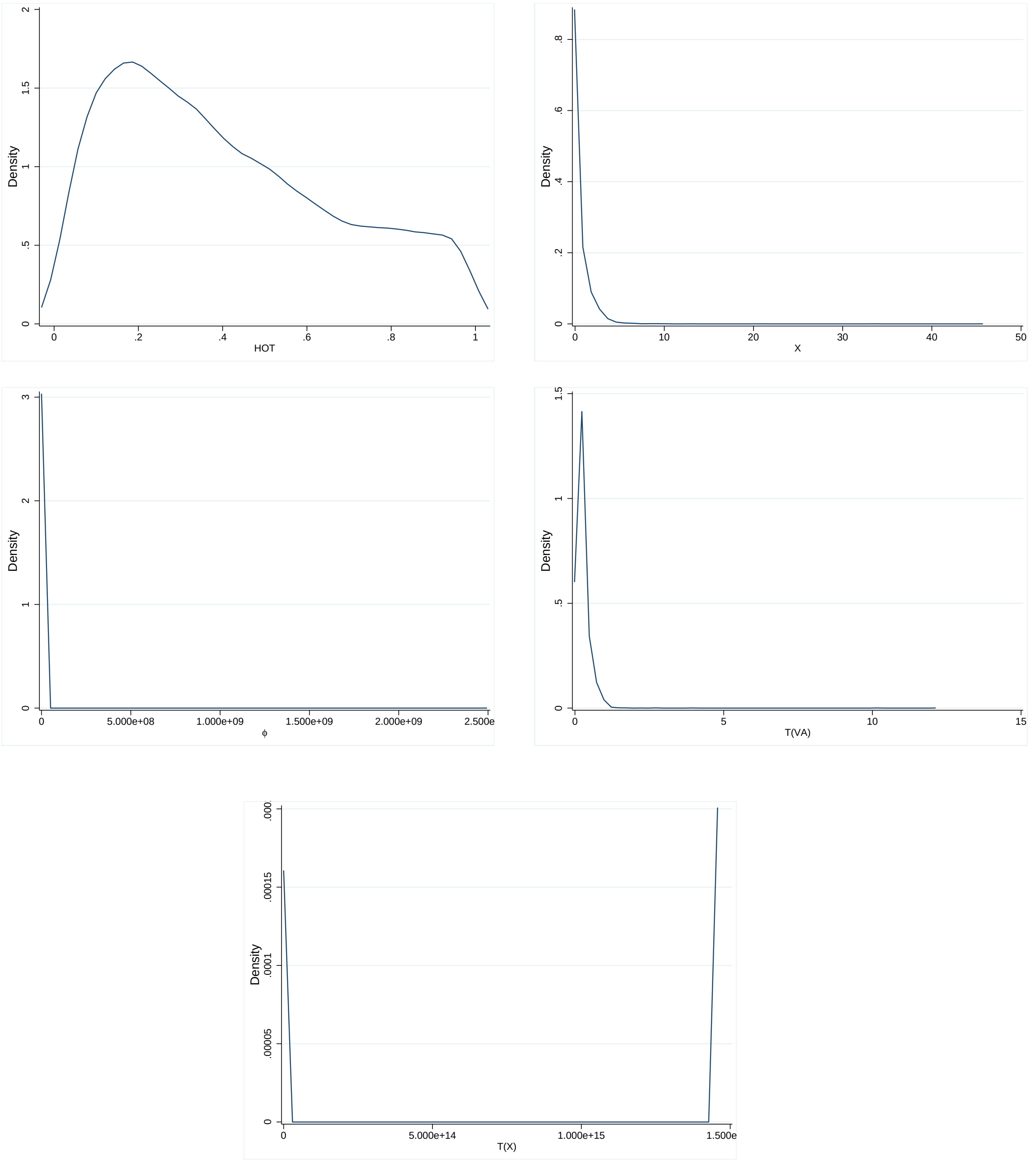

Figure 4: Densities of HOT_i^r, X_i^r, ϕ_i^r, $\mathrm{T}_i^r(\mathrm{VA})$ and $\mathrm{T}_i^r(\mathrm{X})$.

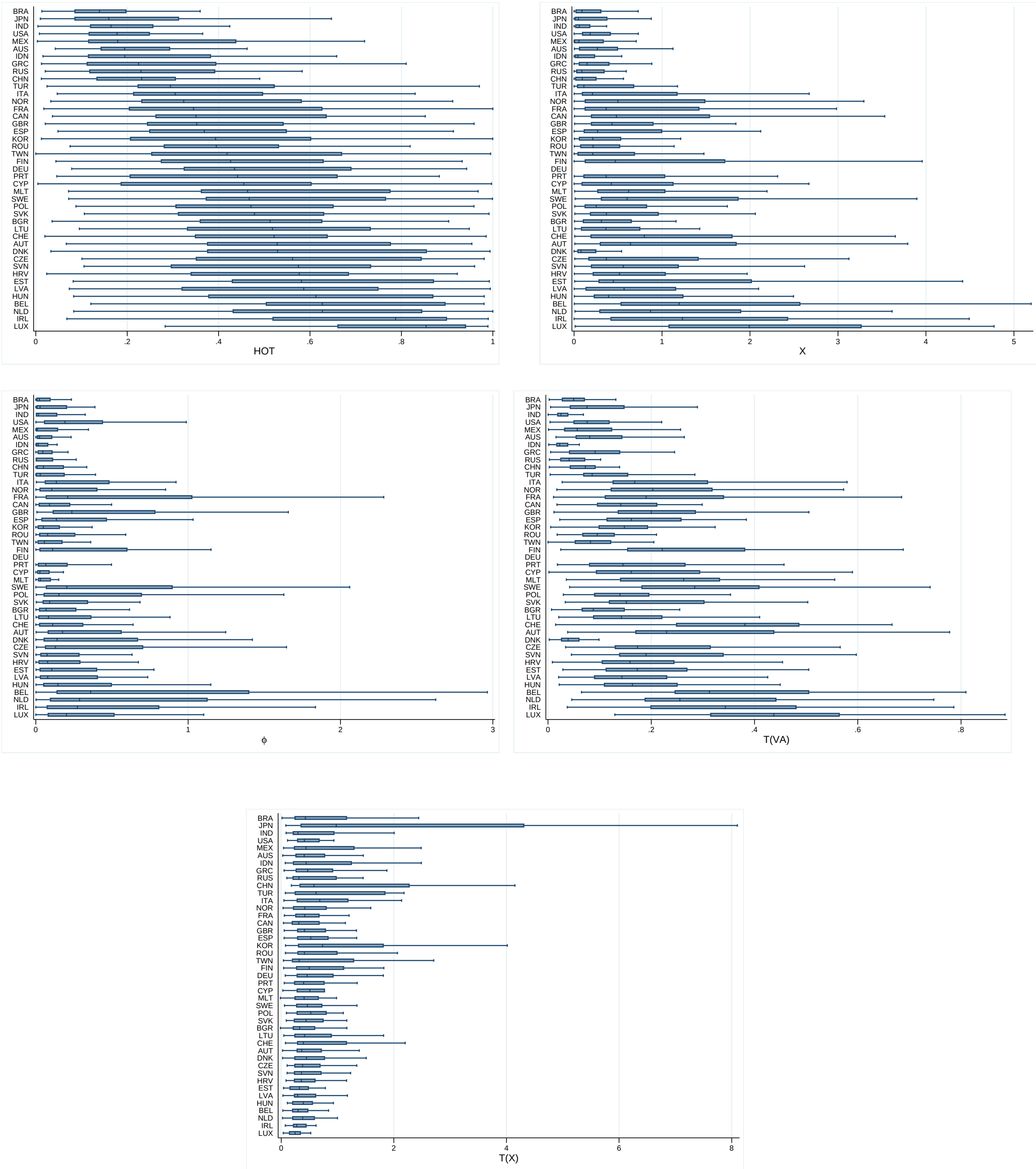

Figure 5: Dispersion of HOT_i^r, X_i^r, ϕ_i^r, $\text{T}_i^r(\text{VA})$ and $\text{T}_i^r(\text{X})$ across sectors for each country in 2014. The mid-point is the median, the thick segment is the interquartile range, and the whiskers are extreme values.

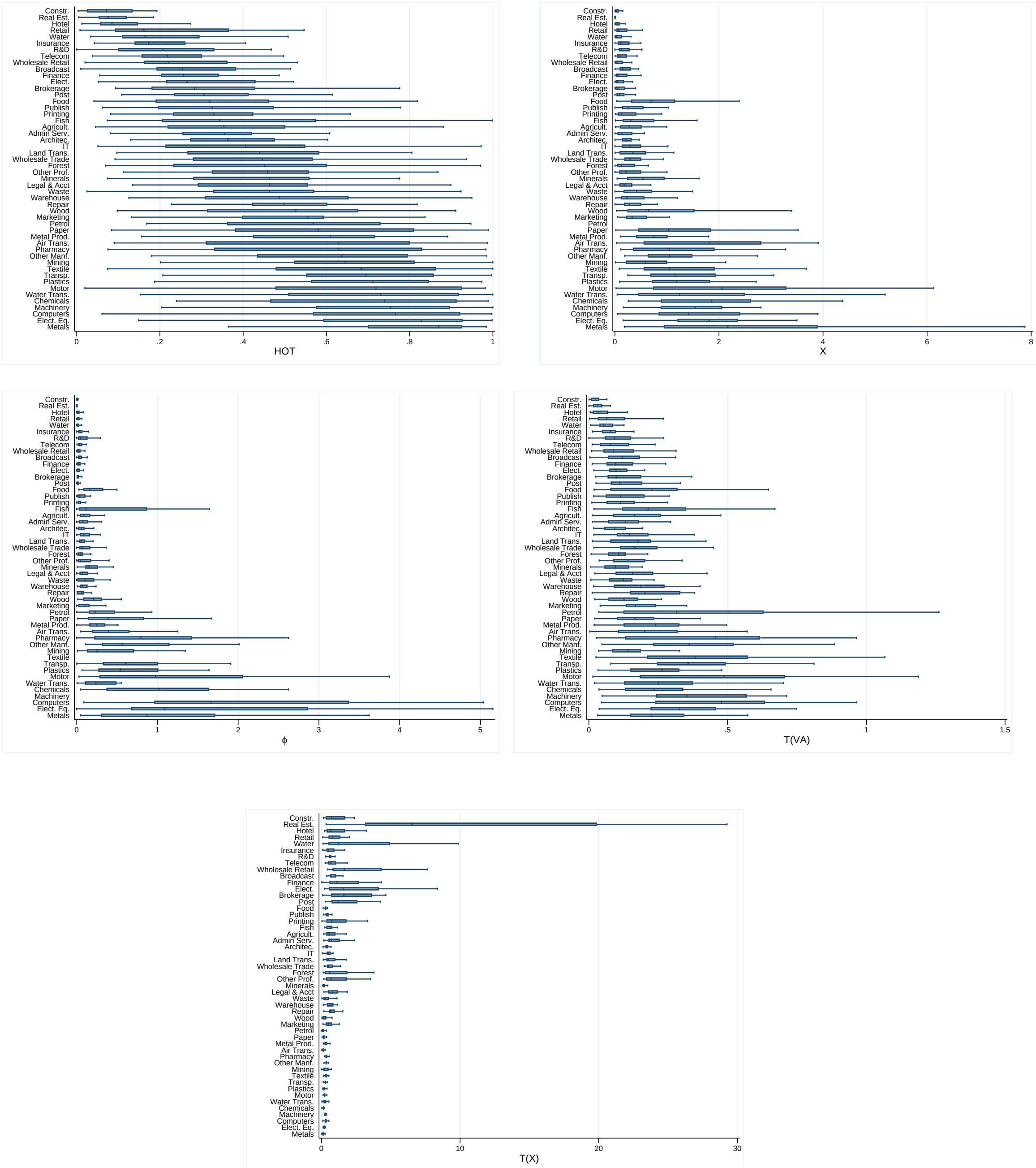

Figure 6: Dispersion of HOT_i^r, X_i^r, $\text{T}_i^r(\text{VA})$ and $\text{T}_i^r(\text{X})$ across countries for each sector in 2014. The mid-point is the median, the thick segment is the interquartile range, and the whiskers are extreme values.

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

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

where in addition

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

Rewriting the resource constraint in matrix algebra making use of the definitions summarized in Definition 2 yields

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

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

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

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:

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

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

and

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

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

By definition in deviation from the steady state, real value added $\ln V_{it}^r$ in country i and sector r is given by

$$\ln \mathrm{V}_{i,t}^r = \ln \mathrm{PY}_{i,t}^r - \ln(\mathrm{P}^c)_{i,t}^r,$$

where we made use of the fact that production is Cobb-Douglas and $\ln(\mathrm{P}^c)_{i,t}^r$ is the log deviation of the price of the final good produced in (i, r). It follows that the vector of value added expressed in deviations from the steady state is given by

$$\begin{aligned}
\ln \mathbf{V}_t &= \boldsymbol{\Lambda}^{-1}\ln \mathbf{Z}_t + \mathcal{P}\boldsymbol{\Lambda}^{-1}\ln \mathbf{Z}_t - ((\mathbf{A}^c)^\top \otimes \mathbf{1}_\mathrm{R})\mathcal{P}\boldsymbol{\Lambda}^{-1}\ln \mathbf{Z}_t \\
&= \frac{1+\psi}{\psi}\ln \mathbf{H}_t,
\end{aligned}$$

where the last equality comes from equation (A.14).

Appendix B

This appendix derives the expressions needed to characterize the responses of all four measures of openness to supply shocks. We derive the responses of $\ln \mathrm{PY}_{i,t}^r$, $\ln \mathrm{PM}_{ij,t}^{rs}$, and $\ln \mathrm{PC}_{ij,t}^r$. We then derive 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

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

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

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

It follows that in deviations from the steady state,

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

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

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

$$\begin{aligned}\ln \mathrm{PC}_{i,t} &= \frac{\sum_r \eta^r\,\mathrm{PY}^r_i \ln \mathrm{PY}^r_{i,t}}{\mathrm{PC}_i} \\ &= \sum_r \upsilon^r_i \ln \mathrm{PY}^r_{i,t},\end{aligned}$$

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

$$\mathrm{PC}^r_{ji} = \pi^r_{ji}\,\mathrm{PC}_i,$$

so that in deviations from the steady state,

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

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

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

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

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

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

$$= \frac{1}{2}\sum_{j\neq i}\frac{(\phi^r_{ij})^{\frac{1}{2}}}{\phi^r_i}\Bigg[\frac{\sum_s b^{rs}_{ij}}{\sum_s b^{rs}_{ij} + bc^r_{ij}}(\ln \xi^{rs}_{ij,t} + \ln \mathrm{PM}^s_{j,t}) + \frac{bc^r_{ij}}{\sum_s b^{rs}_{ij} + bc^r_{ij}}(\ln \pi^r_{ij,t} + \ln \mathrm{PC}_{j,t})$$

$$- \frac{\sum_s b^{rs}_{ii}}{\sum_s b^{rs}_{ii} + bc^r_{ii}}(\ln \xi^{rs}_{ii,t} + \ln \mathrm{PM}^s_{i,t}) - \frac{bc^r_{ii}}{\sum_s b^{rs}_{ii} + bc^r_{ii}}(\ln \pi^r_{ii,t} + \ln \mathrm{PC}_{i,t})$$

$$+ \frac{\sum_s b^{rs}_{ji}}{\sum_s b^{rs}_{ji} + bc^r_{ji}}(\ln \xi^{rs}_{ji,t} + \ln \mathrm{PM}^s_{i,t}) + \frac{bc^r_{ji}}{\sum_s b^{rs}_{ji} + bc^r_{ji}}(\ln \pi^r_{ji,t} + \ln \mathrm{PC}_{i,t})$$

$$- \frac{\sum_s b^{rs}_{jj}}{\sum_s b^{rs}_{jj} + bc^r_{jj}}(\ln \xi^{rs}_{jj,t} + \ln \mathrm{PM}^s_{j,t}) - \frac{bc^r_{jj}}{\sum_s b^{rs}_{jj} + bc^r_{jj}}(\ln \pi^r_{jj,t} + \ln \mathrm{PC}_{j,t})\Bigg]$$

In deviations from the steady state, T(VA) can be written as

$$\ln \mathrm{T}^r_{i,t}(\mathrm{VA}) = \frac{\sum_j\sum_s \lambda^{rs}_{ij}}{\sum_j\sum_s \lambda^{rs}_{ij}(bc^r_{ij} - bc^r_{ii})}(bc^r_{ij}\ln \mathrm{PC}^r_{ij,t} - bc^r_{ii}\ln \mathrm{PC}^r_{ii,t}) - \ln \mathrm{PY}^r_{i,t}$$

$$= \frac{\sum_j\sum_s \lambda^{rs}_{ij} bc^r_{ij}}{\sum_j\sum_s \lambda^{rs}_{ij}(bc^r_{ij} - bc^r_{ii})}(\ln \mathrm{PC}^r_{j,t} + \ln \pi^r_{ij,t}) - \frac{\sum_j\sum_s \lambda^{rs}_{ij} bc^r_{ii}}{\sum_j\sum_s \lambda^{rs}_{ij}(bc^r_{ij} - bc^r_{ii})}(\ln \mathrm{PC}^r_{i,t} + \ln \pi^r_{ii,t})$$

$$- \ln \mathrm{PY}^r_{i,t}$$

In deviations from the steady state, HOT is given by

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

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

Appendix C

We present the 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)
$\ln \text{HOT}^r_{i,t}$	0.103***	0.118***	0.094***	0.032***	0.112***	0.128***	0.014***	0.010***
	(0.006)	(0.006)	(0.006)	(0.003)	(0.006)	(0.007)	(0.001)	(0.001)
$\ln \text{X}^r_{i,t}$		-0.346***		0.540***		-0.131***		0.015
		(0.035)		(0.033)		(0.034)		(0.012)
$\ln \text{T(VA)}^r_{i,t}$		0.202***		-1.434***		0.254***		-0.107***
		(0.033)		(0.021)		(0.020)		(0.017)
$\ln \phi^r_{i,t}$		-0.026***		-0.020***		-0.005**		0.011***
		(0.003)		(0.002)		(0.003)		(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 the log deviation of labour productivity from the steady state, i.e., $\ln\left(\frac{\text{V}^r_{i,t}}{\text{H}^r_{i,t}}\right)$. All the regressors are defined in the text. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\ln \text{HOT}^r_{i,t}$	0.031***	0.035***	0.028***	0.010***	0.033***	0.038***	0.006***	0.003***
	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.000)	(0.000)
$\ln \text{X}^r_{i,t}$		-0.101***		0.163***		-0.042***		-0.007
		(0.010)		(0.010)		(0.010)		(0.005)
$\ln \text{T(VA)}^r_{i,t}$		0.055***		-0.434***		0.089***		-0.036***
		(0.011)		(0.006)		(0.007)		(0.007)
$\ln \phi^r_{i,t}$		-0.007***		-0.007***		-0.001		0.004***
		(0.001)		(0.001)		(0.001)		(0.000)
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 the log deviation of labour productivity from the steady state, i.e., $\ln\left(\frac{\text{V}^r_{i,t}}{\text{H}^r_{i,t}}\right)$. All the regressors are defined in the text. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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

	(1)	(2)	(3)	(4)
$\ln \mathrm{X}^r_{i,t}$	-0.706***	-1.189***	-0.505***	-0.232***
	(0.026)	(0.043)	(0.026)	(0.005)
Obs.	2,000	2,000	2,000	2,000
$\ln \mathrm{T(VA)}^r_{i,t}$	-0.104***	-1.318***	0.177***	-0.264***
	(0.030)	(0.015)	(0.019)	(0.005)
Obs.	2,018	2,018	2,018	2,018
$\ln \phi^r_{i,t}$	-0.017***	-0.009***	-0.006***	0.012***
	(0.002)	(0.003)	(0.002)	(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 the log deviation of labour productivity from the steady state, i.e., $\ln\left(\frac{\mathrm{V}^r_{i,t}}{\mathrm{H}^r_{i,t}}\right)$. All the regressors are defined in the text. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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

	(1)	(2)	(3)	(4)
$\ln \mathrm{X}^r_{i,t}$	-0.214***	-0.367***	-0.154***	-0.069***
	(0.008)	(0.013)	(0.008)	(0.002)
Obs.	2,000	2,000	2,000	2,000
$\ln \mathrm{T(VA)}^r_{i,t}$	-0.053***	-0.401***	0.063***	-0.082***
	(0.010)	(0.004)	(0.006)	(0.002)
Obs.	2,018	2,018	2,018	2,018
$\ln \phi^r_{i,t}$	-0.004***	-0.003***	-0.001	0.004***
	(0.001)	(0.001)	(0.001)	(0.000)
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 the log deviation of labour productivity from the steady state, i.e., $\ln\left(\frac{\mathrm{V}^r_{i,t}}{\mathrm{H}^r_{i,t}}\right)$. All the regressors are defined in the text. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

We present the synchronization regressions for SYNC2, the quasi-correlation coefficient:

Table C.5: Synchronization (Quasi Correlation)

	All sectors (1)	All sectors (2)	Agr-Agr (3)	Agr-Mfg (4)	Agr-Ser (5)	Mfg-Mfg (6)	Mfg-Ser (7)	Ser-Ser (8)
HOT_{ij}^{rs}	0.640***	0.522***	-0.333	-0.699**	-0.239	-0.180	0.908***	1.08***
	(0.064)	(0.071)	(1.10)	(0.320)	(0.300)	(0.190)	(0.120)	(0.110)
X_{ij}^{rs}		0.019	-0.395	-0.101	0.201*	-0.012	0.186***	0.115**
		(0.032)	(0.370)	(0.130)	(0.120)	(0.090)	(0.055)	(0.052)
ϕ_{ij}^{rs}		0.059*	0.514	0.337***	0.099	0.027	0.0004	-0.011
		(0.031)	(0.350)	(0.120)	(0.100)	(0.084)	(0.055)	(0.050)
$\text{T}_{ij}^{rs}(\text{VA})$		0.078**	-0.354	-0.057	-0.008	-0.109	-0.182***	-0.052
		(0.033)	(0.520)	(0.140)	(0.150)	(0.079)	(0.055)	(0.055)
Obs.	26,071,229	22,546,820	68,723	982,452	1,023,281	3,671,535	8,029,573	4,555,345

Note: The dependent variable is quasi correlation of $\log(\frac{VA_i^r}{N_i^r})$ and $\log(\frac{VA_j^s}{N_j^s})$. Value Added is in real PPP USD. The regressions are performed with reghdfe in STATA, which allows for multiple level fixed effects (see Correia, 2017). Robust standard errors in parentheses, clustered at country-sector pair level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. All coefficients and standard errors have been multiplied by 100 for legibility.

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 Productivity

Productivity is calculated as the logarithm of real PPP USD sector level value added per employee. 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, the number of employees is in thousands. 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 Initial Value Added

Initial value added is computed as the logarithm of sector level value added per employee, in real PPP USD, measured in 2000. The data are sourced from WIOD SEA and the OECD.

D.5 Business Cycles Synchronization

SYNC1 is measured as minus the absolute pairwise difference in the logarithm of real value added growth between country-sector pairs, measured each year. SYNC2 is the demeaned product of real value added growth between country-sector pairs divided by each country-sector standard deviations. 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.6 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 $\text{PM}_{ij}^{rs} + \text{PM}_{ji}^{rs}$ to $\text{VA}_i^r + \text{VA}_j^r$ 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.7 Trade in Value Added (TiVA): T_i^r and T_{ij}^{rs}

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