DISTORTIONS AND THE STRUCTURE OF THE WORLD ECONOMY

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Distortions and the Structure of the World Economy†

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We model the world economy as one system of endogenous input-output relationships subject to frictions and study how the world's input-output structure and world's GDP change due to changes in frictions. We derive a sufficient statistic to identify frictions from the observed world input-output matrix, which we fully match for the year 2011. We show how changes in internal frictions impact the whole structure of the world's economy and that they have a much larger effect on world's GDP than external frictions. We also use our approach to study the role of internal frictions during the Great Recession of 2007–2009. (*JEL* D57, E16, E23, E32, F41, G01)

Wassily Leontief in his Nobel Lecture (Leontief 1974) argued, "The world economy, like the economy of a single country, can be visualized as a system of interdependent processes." In this paper, we develop a model of the world economy as input-output relationships subject to frictions.

We study the input-output relationships where the base unit is a country-sector pair. Rather than considering input-output relationships within countries and trade relationships across countries, we model the world economy as one world input-output matrix. Moreover, the structure of the economy, that is, the world input-output matrix, is endogenous, as the expenditure shares depend on sectoral frictions and TFPs and change with them. As a result, we can study the aggregate effects of changes in frictions and compute the elasticity of world GDP to changes in frictions across countries and sectors.

In addition, we derive two main analytical results. First, we propose a methodology to decompose frictions from sectoral TFPs. Specifically, we derive simple closed-form sufficient statistics for frictions as the functions of the small set of directly observable sectoral input expenditure shares and the final goods consumption shares. In doing so, we discuss the assumptions under which we can identify the frictions: CES production and consumption shares, the values of the elasticities of substitution, time-invariant demand shifters, and a normalization of the

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within-sector friction. The frictions we identify may be technological in nature, such as physical trade costs or shifters in the demand from intermediate inputs, or they may reflect distortions in the transactions of inputs across sectors. We also show that if technological frictions are slow moving, the change in frictions identifies changes in distortions.

We identify the frictions by considering a model with the CES production for intermediate goods and the CES consumption structure rather than the Cobb-Douglas form considered in Jones (2011, 2013); Acemoglu et al. (2012); and Caliendo and Parro (2015). This CES structure is precisely what defines an endogenous input-output structure of the economy that allows us to identify the frictions and the TFPs separately. Intuitively, the endogenous input expenditure and consumption shares are affected by the frictions and TFPs differently, and we can use these different effects to separately identify frictions and TFPs. The use of both the production and the consumption side of the economy and the CES structure are important. If only the production side is used, under the CES production, we can only identify a combination of frictions and TFPs. The consumption side under the CES gives the ratio of sectoral prices in terms of the consumption shares that allows us to identify the frictions and TFPs separately, as we show later on. The intuition also highlights the generality of the method—we can identify as many objects of interest as there are endogenous shares. In our case, the input and the consumption shares are endogenous; hence, we can identify both the country-sector TFPs and the frictions.[1]

Our second theoretical result is to analytically derive the elasticity of the changes in the input-output shares to the changes in the frictions and TFPs in terms of the functions of the small set of directly observable sectoral input expenditure shares. That is, we find an elasticity of the shares of inputs of intermediate goods of a country-sector pair (say, the Basic Metals and Fabricated Metal sector in China) to the change in the frictions or TFPs in another country-sector pair (say, the frictions in the Financial Intermediation sector in the United States). In other words, we characterize the change in the entire world's input-output matrix structure to the change in a given country-sector pair's TFP or frictions. Importantly, we have that the elasticity of input-output shares is nonzero and nonconstant and depends on the interconnection of sectors in the input-output structure. We further discuss how to decompose these elasticities into the direct effects of changes in the frictions on expenditure shares, and the indirect effects from changes in the prices of intermediate goods.

We now turn to the quantitative results of the paper. We derive all the data needed to measure frictions and to compute the elasticities from the World Input-Output Database (WIOD) that traces the flow of goods and services across 35 industries, 40 countries, and a constructed rest of the world, over the period 1995–2011. Overall, we compute more than half a million internal frictions over this period and about 2 million elasticities of input-output shares and the world's GDP to changes in frictions.

In our model, changes in frictions impact wages and prices in the whole world economy, and the input-output shares across all sectors and all countries may change

[1] We also discuss how the model then can accommodate a number of additional dimensions of heterogeneity.

as a result. We first study how changes in the internal frictions affect the endogenous structure of the economy of individual countries. For the United States' and China's input-output tables, we compute how their own input-output structure changes with respect to changes in their own internal frictions. These two countries are chosen as important illustrative examples with different input-output structures, but, of course, we could have chosen a set of any other countries. We show that the quantitative effects follow the analytical results from the closed-form elasticities. Consider the reduction in internal frictions of, for example, manufacturing industries. The share of manufacturing inputs by all sectors increases because of the direct effects of the lower friction, the indirect effects on the price of manufacturing inputs, and the substitution effect of other sectors becoming more expensive. We then compute the effects on the US input-output structure from changes in internal frictions in China—the cross elasticity of the US economy structure to Chinese frictions.

Our second exercise is to compute the global elasticity of expenditure shares and elasticity of the world's real GDP to changes in internal frictions. Specifically, we compute the change in expenditure shares in all countries and sectors in the world from a 10 percent reduction in internal frictions all over the world. The main conclusion is that changing all internal frictions at the same time results in an even more dramatic change in the world's input-output structure, which reinforces our findings for the individual countries.

Even more starkly, the importance of internal frictions can be seen by ranking the top 60 elasticities of the world's GDP to the frictions of a sector in a given country. As an example of the importance of internal frictions for the global economy, we find that the elasticity of China's construction sector has about three-fourths the magnitude of the elasticity of the world's GDP to *all* of the external frictions in the United States. Of course, the elasticity of the world's GDP to changes in internal frictions in a given sector can be large because the share of the sector in the world's GDP is large or because the internal friction has a large impact on the global economy as a result of the country and industry interconnections. Therefore, we also decompose the contribution to the world's GDP elasticity of the own sector that experiences the change in frictions; the contribution of the domestic production network, namely, the contribution of other sectors in the domestic economy; and the contribution of the external network, namely, the effects of changes in GDP in other countries. We find that the relative contribution of each of these components is very heterogeneous across countries and industries. For instance, in the construction sector in China, most of the world's GDP elasticity is explained by the own-sector contribution, but in other important sectors for the world's economy, such as electrical equipment in China, the domestic and external networks are much more important.

We then compute the elasticity of the world's GDP with respect to external frictions. The principal result here is that the elasticity of internal frictions is an order of magnitude larger than the elasticity of external frictions. This is connected to our findings for the individual countries that the domestic input-output relations tend to be more important than cross-country input-output relations. Our result also holds even if we normalize these elasticities by the size of each country. The closest in terms of the result on the internal versus external frictions is the work by Tombe and Zhu (2019). They show that for China, internal frictions play a much larger role in aggregate productivity and output. We also show how the magnitude of these elasticities changes for different periods of time, which highlights one of our previous messages, namely that the elasticity of the world's GDP to changes in internal frictions is not constant but depends on the global input-output structure. In addition, one important aspect of our approach is that the computation of elasticities to changes in frictions and TFP requires to keep track of the observable global production structure (world's input-output table), but it does not require to identify the frictions or TFPs.

Next, we compute the frictions and the TFPs for all of the country-sectors in the world economy for the period 1995–2011. Our principal finding is that there is a significant heterogeneity in the growth rate of the frictions and their distribution across countries. Therefore, aggregate measures of relative frictions across countries can give only a partial view of the degree of frictions across countries since the country-level frictions mask the high heterogeneity at the more disaggregate level.

We then compute the change in global input-output shares and the world's real GDP to the actual changes in domestic frictions over the period 1995–2011. In other words, we show how the world's input-output structure in 2011 would have changed if internal frictions were set to their 1995 level. As we have emphasized above, the world input-output structure shows complex interconnections across sectors and countries, and these interconnections respond endogenously to changes in frictions. We observe significant changes in the domestic input-output relationships; that is, those would have been more important today if frictions would have stayed at the level of 1995. We also see quite heterogeneous effects across countries, reinforcing our view on the importance of seeing the world as a single input-output structure with complex interrelations. Notably, we highlight more clearly how China would have been less connected to the rest of the world as a supplier and seller.[2] Consistent with the heterogeneity in the growth rate of internal frictions, we find a differential impact on world's GDP to the actual change in local frictions across sectors and countries.

Finally, we apply our model and methodology to study the implication of internal frictions for the trade collapse during the Great Recession of 2007–2009. We provide new results to the literature on the trade collapse during the Great Recession (e.g., Alessandria, Kaboski, and Midrigan 2013; Levchenko, Lewis, and Tesar 2010; Eaton et al. 2016). First, we document the change in external trade and (not relative to) internal trade during the Great Recession, different from the literature that has mostly looked at the collapse in international trade relative to production. Second, different from the literature that has focused on studying the role of external frictions, with our framework, we study the role of internal frictions on the observed change in internal and external trade during this period. The fact that in our framework internal trade can be impacted by changes in internal frictions, which in turn can affect external trade since sectors and countries are interconnected through the endogenous world's input-output structure, allows us to study the role of internal frictions on internal trade and external trade during the Great Recession. In fact, how internal frictions can potentially impact the whole input-output structure (domestic and international transactions) is one main message that we highlight in

[2] Adamopoulos et al. (2017) and Brandt, Kambourov, and Storesletten (2016) are the recent analyses of the evolution of frictions in China at the firm and sectoral level.

different sections of the paper. We find that the role that changes in internal frictions had in internal and external trade was relevant but heterogeneous across regions. As an example, we find that in the United States, the changes in internal frictions explain about 4.5 percent of the decline in external trade and about 22.4 percent of the decline in internal trade during the Great Recession.

Beyond the connection to the literature discussed in the previous paragraphs, our model of the world input-output matrix is also related to recent work by Antrás and de Gortari (2020), who develop a structural model to study global supply chains that also matches the input-output structure of the world economy. While their model with multiple stages of production is aimed at studying the formation of global supply chains, our focus is on identifying internal frictions and studying their effects on the world's input-output structure. Our paper is also closely related to the macroeconomic literature that emphasizes domestic frictions (misallocation) across sectors and firms (e.g., Restuccia and Rogerson 2008, 2013; Hsieh and Klenow 2009).[3] This strand of the literature has encountered difficulties with regard to separating frictions from TFPs, as argued in Jones (2011, 2013). Our model with the CES production for intermediate goods and the CES consumption structure allows us to identify frictions, as we described above. Our paper complements recent studies that show how local productivity shocks or frictions spread within a country (see, e.g., Caliendo et al. 2018; Fajgelbaum et al. 2019) and the literature on aggregate consequences of idiosyncratic shocks that emphasizes the departure from the Cobb-Douglas assumptions in the context of closed economy models (Atalay 2017; Baqaee and Farhi 2019; and Carvalho et al. 2021). Finally, our paper also relates to Atkeson and Burstein (2010), who argue that only the microeconomic evidence on the firm responses is not sufficient to estimate the aggregate welfare effects of the changes in trade costs. Atkeson and Burstein (2017) further develop sufficient statistics for the aggregate effects of innovation. While our model is static and we do not consider innovation, we share the same principle of analyzing primarily the aggregate and general equilibrium effects of frictions.

The paper is organized as follows. In Section I, we present our model of the input-output structure of the world economy and derive our main theoretical results: the sufficient statistics to identify frictions. In Section II, we take the model to the data, compute the elasticities of the world's input-output structure, and the world's GDP to changes in internal frictions. We also compute the changes in internal frictions and their impact on the global economy. In Section III, we apply our framework to study the role of internal frictions during the Great Recession. Finally, Section IV concludes. All the derivations of the theoretical results, detailed explanations of the data sources, extensions of the model, and additional results are relegated to the online Appendix.

[3] Bartelme and Gorodnichenko (2015); Boehm (2015); Fadinger, Ghiglino, and Teteryatnikova (2015) develop various empirical proxies for frictions in an input-output setting.

I. A Model of Input-Output Relationships with Frictions

We first focus on the identification of internal frictions that impact domestic transactions across sectors. To do so, we start with a closed economy model. Later on, we derive the results for the open economy model with multiple countries.

A. *Closed Economy*

The economy is endowed with a unit of equipped labor and the unit mass of agents.[4] There are a discrete J number of productive sectors (indexed by j,k). Goods from sector j, denoted by Q_j, are produced with a Cobb-Douglas production function:

$$Q_j = A_j L_j^{\beta_j} M_j^{(1-\beta_j)},$$

where A_j is the TFP, L_j is the amount of labor allocated to sector j, M_j is the amount of materials used by the sector j, and $\beta_j \in [0,1]$ is the share of value added in gross output. Generically, goods Q_j are used for final consumption as well as for the production of materials, as we describe next.

Materials in sector j, M_j, are a CES aggregate of intermediate goods from all sectors, namely,

$$M_j = \left(\sum_k \iota_{jk} Q_{jk}^{\frac{\theta}{1+\theta}}\right)^{\frac{1+\theta}{\theta}},$$

where $k = 1, \ldots, J$ and the sector j sources Q_{jk} of intermediate goods from the sector k. The input weight ι_{jk} captures the relative importance of different intermediate goods from sector k in the production of materials in sector j. There is perfect competition in all sectors.[5]

We assume free mobility of labor across the sectors. The feasibility condition for labor is then given by

$$\sum_{j=1,\ldots,J} L_j = 1.$$

The unit price of good Q_j is given by

$$c_j = \frac{1}{A_j} w^{\beta_j} P_j^{(1-\beta_j)},$$

[4] The method we develop below to characterize frictions and TFPs does not depend on the size of population in each country. When computing the general equilibrium effects from changes in frictions, we account for the difference in population across countries.

[5] This assumption is also not essential as, for example, heterogeneous markups represent themselves as the sector-level frictions.

where w is the wage (factor payments) and P_j denotes the price of materials in sector j.

An agent in country i maximizes the CES utility

$$U(C) = \left(\sum_{j=1,\ldots,J} \chi_j C_j^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where C is the composite consumption good, C_j are the consumption goods from sector j, and χ_j are relative weights in demand for goods from each sector j. We assume throughout that preferences are stable, namely that individuals facing the same choices at different points in time will have the same preferences, and that χ_j are also stable over time.

Sourcing goods across sectors is costly and subject to frictions. In particular, sourcing a good from sector k to sector j entails a cost $\kappa_{jk} c_k$. We call κ_{jk} a friction and note that we do not impose symmetry: $\kappa_{jk} \neq \kappa_{kj}$. These frictions may be technological in nature (e.g., physical trade costs of moving goods across industries in different locations) or distortions (regulations, policies that favor sourcing from one sector over another, markups, quotas, etc.).[6]

We assume that such frictions do not depend on whether goods are used for final consumption or for production of intermediate goods. As a result, frictions in final goods are the same as in intermediate goods.

We further define two types of key statistics that we use throughout the paper. Denote the share of inputs from sector k in total intermediate consumption in sector j by γ_{jk}. Formally,

$$\gamma_{jk} \equiv \frac{X_{jk}}{\sum_{h=1}^{J} X_{jh}},$$

where X_{jk} is expenditure in sector j on intermediate goods from sector k. The intermediate expenditure shares γ_{jk} have a direct counterpart in the data, as they are exactly the input-output shares that can be directly computed from any input-output table, as we show later.

Denote the share of consumption of the consumption good from sector j in aggregate consumption by α_j. Formally,

$$\alpha_j \equiv \frac{P_j C_j}{\sum_{k=1}^{J} P_k C_k}.$$

[6] We model these frictions as iceberg-type costs. The model can also accommodate frictions modeled as taxes, which would require to take into account revenues in the model's market-clearing conditions, which is straightforward to do. Importantly, tax revenues do not matter for the formulas to compute internal frictions that we derive later on.

Similar to the intermediate expenditure shares γ_{jk}, the final expenditure shares α_j are directly observable in any input-output matrix that contains data on final expenditure.

In the next section, we show how to use the structure of the model to identify the input-output frictions.

B. *Sufficient Statistics for Identification of Frictions*

In this section, we propose a method to identify frictions and TFPs in the input-output economy. The key to the results is threefold. First, the CES structure of both production of the intermediate goods and consumption yields the expenditure shares γ and consumption shares α varying with frictions and TFP. Second, frictions and TFP affect the production and consumption shares differently, hence allowing to separately identify these two objects. Third, using the consumption shares allows us to substitute for prices with the consumption shares α.

We start with the production side of the economy. We define $\tau_{jk} = \kappa_{jk}\left(\iota_{jk}\right)^{-(1+\theta)/\theta}$ as the friction that prevents the use of inputs from sector k in the production of sector j, due to either distortions or technological frictions. We assume that $\tau_{jj} = 1$, and therefore, the frictions across sectors we identify later on are relative to the within-sector friction. The share of the input of the sector k in the sector j is

$$\gamma_{jk} = \frac{\left(\tau_{jk} c_k\right)^{-\theta}}{\sum_{h=1}^{J}\left(\tau_{jh} c_h\right)^{-\theta}},$$

which in turn can be written as

$$\gamma_{jk} = \frac{A_k^{\theta}\tau_{jk}^{-\theta}P_k^{-\theta(1-\beta_k)}}{\left(P_j/w^{\beta_k}\right)^{-\theta}}, \tag{2}$$

where the sectoral price index is given by

$$P_j = \left(\sum_{h=1}^{J} A_h^{\theta}\tau_{jh}^{-\theta} w^{-\theta\beta_h} P_h^{-\theta(1-\beta_h)}\right)^{-1/\theta}.$$

Dividing the input shares, γ_{kk} and γ_{jk}, to cancel the sector k TFP, A_k, and the wage, w, and using that $\tau_{kk} = 1$, we get the expression for the frictions as a function of the sectoral prices:

$$\tau_{jk} = \left(\frac{P_j}{P_k}\right)\left(\frac{\gamma_{kk}}{\gamma_{jk}}\right)^{\frac{1}{\theta}}.$$

Substituting for the definition of the sectoral price index, we obtain an expression for the composite of the frictions and the ratio of the sectoral TFPs:

$$\tilde{\tau}_{jk} \equiv \tau_{jk}\frac{\left(A_j\right)^{1/\beta_j}}{\left(A_k\right)^{1/\beta_k}} = \left(\frac{\gamma_{jj}^{1/\beta_j}}{\gamma_{kk}^{1/\beta_k}}\right)^{\frac{1}{\theta}}\left(\frac{\gamma_{kk}}{\gamma_{jk}}\right)^{\frac{1}{\theta}};$$

therefore, $\tilde{\tau}_{jk}$ can be identified but not the TFPs and frictions separately. In other words, by only using the cross-sectoral variation in input-output production shares, we can only identify a combination of frictions and TFPs. In order to separate frictions from TFPs, we now turn to the consumption side of the economy.

The consumer's problem yields the following consumption share sector j:

$$\alpha_j = \frac{P_j C_j}{\sum_{k=1}^{J} P_k C_k} = \chi_j \left(\frac{P_j}{P}\right)^{1-\sigma}, \tag{3}$$

where

$$P = \left(\sum_{j=1,\ldots,J} \chi_j \left(P_j\right)^{1-\sigma}\right)^{1/(1-\sigma)} \tag{4}$$

is the ideal price index.

Dividing the shares of consumption for sectors j and k gives the ratio of sectoral prices:

$$\frac{P_j}{P_k} = \left(\frac{\alpha_j/\chi_j}{\alpha_k/\chi_k}\right)^{\frac{1}{1-\sigma}},$$

and after substitution, the expression for the friction we obtain (see online Appendix C for the derivation):

$$\tau_{jk} = \left(\frac{\gamma_{kk}}{\gamma_{jk}}\right)^{\frac{1}{\theta}} \left(\frac{\alpha_j/\chi_j}{\alpha_k/\chi_k}\right)^{\frac{1}{1-\sigma}}.$$

Another way to gain intuition is to rewrite

$$\tau_{jk} \left(\frac{\alpha_k/\chi_k}{\alpha_j/\chi_j}\right)^{\frac{1}{1-\sigma}} = \left(\frac{\gamma_{kk}}{\gamma_{jk}}\right)^{\frac{1}{\theta}}.$$

Hence, the friction is the wedge in the first-order condition, whereas the frictionless economy equates the relative consumption shares to the input shares.

The next proposition establishes the conditions to identify changes in frictions and TFP over time.

PROPOSITION 1: *Let* $\hat{\tau} \equiv \tau_{t+1}/\tau_t$ *and more generally any variable with "hats" be changes over time. The change in internal frictions faced by sector j to source goods from sector k is given by*

$$\hat{\tau}_{jk} = \frac{\left(\hat{\gamma}_{kk}/\hat{\gamma}_{jk}\right)^{\frac{1}{\theta}}}{\left(\hat{\alpha}_k/\hat{\alpha}_j\right)^{\frac{1}{1-\sigma}}}.$$

And the change in TFP relative to a reference sector k can be recovered as

$$\hat{A}_j = \left(\frac{\hat{\gamma}_{jj}^{1/\beta_j}}{\hat{\gamma}_{kk}^{1/\beta_k}}\right)^{\frac{\beta_j}{\theta}} \left(\frac{\hat{\alpha}_k}{\hat{\alpha}_j}\right)^{\frac{\beta_j}{1-\sigma}}.$$

The proposition above gives a simple closed-form expression for the sufficient statistics formula to identify the change in internal frictions separately from the TFPs over time. All of the formulas are expressed in terms of the set of directly observable empirical counterparts. The key to our identification is (a) stable preferences (as defined before), (b) information of the elasticities θ and σ, and (c) the use of both the consumption and the production shares to separate frictions from TFPs, and (d) a normalization of the within-sector friction that we mentioned above. In addition, if technological frictions are much more slow moving than distortions, the changes in frictions in fact identify changes in distortions. We formalize this result in the following corollary:

COROLLARY 1: *If technological frictions are time-invariant, then* $\hat{\tau}_{jk}$ *identify changes in distortions.*

The key to the analysis is that we use both the consumption and the production shares to separate frictions from TFPs. As a result, we can identify as many elements of the model (i.e., frictions and TFPs) as there are observable shares of consumption and production. Otherwise, only the composite frictions $\tilde{\tau}_{jk}$ can be identified. In addition, Corollary 1 shows that if technological frictions move more slowly relative to distortions, we can then also identify the changes in distortions across sectors and over time.

We now proceed to show how to identify frictions in a model of the world's input-output relationships with internal and external frictions.

C. *Open Economy*

The world economy consists of N countries (indexed by i,n). We maintain the assumption that each economy has J sectors (indexed by j,k) and is endowed with one unit of equipped labor and the unit mass of agents. The production technologies are the same as in the closed economy, where we now index variables by the country subscripts. Namely, good producers have Cobb-Douglas production function

$$Q_{ij} = A_{ij} L_{ij}^{\beta_{ij}} M_{ij}^{(1-\beta_{ij})},$$

where A_{ij} is the TFP of country i and sector j and L_{ij} and M_{ij} are labor and materials used by the sector j, with $\beta_{ij} \in [0,1]$.

We maintain the assumption that Q_{ij} are used for final consumption as well as for the production of materials and that agents in country i have preference over home final sectoral goods Q_{ij} as in (1). Materials in country i and sector j, M_{ij}, are a CES aggregate of intermediate goods from all sectors and locations, namely,

$$M_{ij} = \left(\sum_{n,k} \iota_{ij,nk} Q_{ij,nk}^{\frac{\theta}{1+\theta}} \right)^{\frac{1+\theta}{\theta}},$$

where $n = 1,..,N$; $k = 1,\ldots,J$, and the sector i in the country j sources $Q_{ij,nk}$ of intermediate goods from the sector k in the country n. The input weight $\iota_{ij,nk}$ captures the relative importance of different intermediate goods from sector k and country n in the production of materials in sector j and country i. We maintain the assumption of free labor mobility across sectors, but not across countries, and of perfect competition in all sectors.

Sourcing goods across sectors within a country is subject to internal frictions in the way it was described in the closed economy version of the model. In addition, we assume that sourcing goods across countries is subject to external frictions. We define $\tau_{ij,nk} = \kappa_{ij,nk}\left(\iota_{ij,nk}\right)^{-(1+\theta)/\theta}$ as frictions that prevent the use of inputs from sector k and country n in the production of sector j and country i. In an open economy, the share of the input of the sector k in the sector j in country i is

$$\gamma_{ij,ik} = \frac{\left(\tau_{ij,ik} c_{ik}\right)^{-\theta}}{\sum_{m=1}^{N}\sum_{h=1}^{J}\left(\tau_{ij,mh} c_{mh}\right)^{-\theta}}, \tag{5}$$

while the sectoral price index is given by

$$P_{ij} = \left(\sum_{m=1}^{N}\sum_{h=1}^{J} A_{mh}^{\theta}\tau_{ij,mh}^{-\theta} w_m^{-\theta\beta_{mh}} P_{mh}^{-\theta(1-\beta_{mh})}\right)^{-1/\theta}. \tag{6}$$

We now present the open economy counterpart results to Proposition 1.

PROPOSITION 2: *In a world with N countries $(indexed\ by\ i,n)$ and J sectors $(indexed\ by\ j,k)$, the change in internal frictions is given by*

$$\hat{\tau}_{ij,ik} = \frac{\left(\hat{\gamma}_{ik,ik}/\hat{\gamma}_{ij,ik}\right)^{\frac{1}{\theta}}}{\left(\hat{\alpha}_{ik}/\hat{\alpha}_{ij}\right)^{\frac{1}{1-\sigma}}}.$$

The change in external frictions is given by

$$\hat{\tau}_{ij,nk} = \frac{\left(\hat{\gamma}_{nk,nk}/\hat{\gamma}_{ij,nk}\right)^{\frac{1}{\theta}}}{\left(\hat{\alpha}_{nk}/\hat{\alpha}_{ij}\right)^{\frac{1}{1-\sigma}}}\left(\frac{\hat{P}_i}{\hat{P}_n}\right),$$

and the change in TFP relative to a reference sector k can be recovered as

$$\hat{A}_{ij} = \left(\frac{\hat{\gamma}_{ij,ij}^{1/\beta_{ij}}}{\hat{\gamma}_{ik,ik}^{1/\beta_{ik}}}\right)^{\frac{\beta_{ij}}{\theta}}\left(\frac{\hat{\alpha}_{ik}}{\hat{\alpha}_{ij}}\right)^{\frac{\beta_{ij}}{1-\sigma}}.$$

Proposition 2 presents the sufficient statistics formula to identify the change in external and internal frictions separately from the TFPs. As we can see, all of the formulas are expressed in terms of the set of directly observable empirical counterparts from a world input-output table. Proposition 2 relies on the same identifying assumptions that we assumed in the closed economy model.

The setting under which we derive our formulas assumes a symmetric CES structure, which has the advantage that only two CES elasticities are required to compute the changes in internal frictions. In online Appendix D, we present other extensions of our results. In particular, we derive the formula to compute internal frictions with a nested CES structure where domestic inputs and foreign inputs aggregate with different elasticities of substitution, as well as another more general extension with an arbitrary number of nests across inputs. Importantly, we show that conditional on knowing the values of the elasticities of substitution of the different nests, the formula is still a function of observable production and consumption shares, and the identification of frictions does not require additional assumptions. Computing the changes in internal frictions in a nested CES framework does require, however, estimates of additional elasticities of substitution across inputs.[7]

We comment on the two key differences with the results of the macroeconomic literature that focuses on misallocations and frictions—the use of the CES production function and the use of the CES consumption function. In Hsieh and Klenow (2009), the production function is Cobb-Douglas. They identify the frictions by making reference to the frictionless country. This amounts in our context to assuming that either the net (of friction) as well as gross (with friction) prices are observable or that the country/sector pairs have the same Cobb-Douglas elasticities of inputs. Jones (2011, 2013), which are the closest to our study, also use the Cobb-Douglas production in the input-output structure and hence, cannot separate the TFPs from the frictions. Besides, Cobb-Douglas assumption implies that the expenditure and the consumption shares are exogenous and do not change with frictions and TFPs.[8]

It is also immediately clear how to extend the analysis to the cases of the commonly used trade models. In particular, a wide class of trade models (e.g., Anderson and van Wincoop 2003; Eaton and Kortum 2002; Melitz 2003; among many others) deliver a gravity equation of type of equation (5) but for the case of cross-country flows in a given sector (that is, when $i \neq n$ and $k = j$). It immediately follows that our sufficient statistic can be directly mapped to gravity-trade models to infer trade costs.

D. *Endogenous Input-Output Structure*

One important feature of our model is that the input-output matrix is endogenous, which results from our CES structure. In this section, we study how the world's input-output structure changes with changes in frictions. The counterpart of input-output shares $\gamma_{ij,nk}$ in our model is given by (5), which in turn can be written as

$$\gamma_{ij,nk} = \frac{A_{nk}^{\theta} \tau_{ij,nk}^{-\theta} P_{nk}^{-\theta(1-\beta_{nk})}}{\left(P_{ij}/w_n^{\beta_{nk}}\right)^{-\theta}}, \tag{7}$$

[7] As another extension, in online Appendix D we also show how we can identify internal frictions in a model with sale taxes. In particular, we show that a sales tax levied on sales of output of sector k affects the bilateral expenditure shares of all sectors that buy from sector k, and therefore it differentiates out in our sufficient statistic formula that takes the cross-sectoral expenditure shares. In addition, we also show that introducing skill-biased technical change does not affect the sufficient statistic formula. The intuition is that a skill-biased technology enters in the labor input in the production function and alters the labor shares of skilled and unskilled labor, which differentiate out in our formulas to identify frictions.

[8] Both CES and Cobb-Douglas are subject to a similar limitation that one cannot account for the formation of new input-output relations, that is, input-output shares that change from zero to positive. However, at the level of aggregation that we work in the empirical section, these cases are negligible.

where, as stated above, the sectoral price index is given by (6). It follows that the elasticity of input-output share $\gamma_{ij,nk}$ with respect to frictions $\tau_{ij,nk}$ for all i, j, n, k is given by

$$\frac{d\log\gamma_{ij,nk}}{d\log\tau_{ij,nk}} = -\theta + \theta\frac{d\log P_{ij}}{d\log\tau_{ij,nk}} - \theta\left(1-\beta_{nk}\right)\frac{d\log P_{nk}}{d\log\tau_{ij,nk}} - \theta\beta_{nk}\frac{d\log w_n}{d\log\tau_{ij,nk}}.$$

Accordingly, the elasticity of input-output shares $\gamma_{ij,nk}$ with respect to changes in frictions depends on three forces. First, there is a direct effect on the sector-country that experiences the change in frictions, with an elasticity of $-\theta$. Second, it depends on the indirect price effects of changes in frictions anywhere. Third, it depends on the general equilibrium effects on local wages.

More generally, we can express the elasticity of the whole world's input-output structure with respect to changes in frictions and productivities in terms of the primitives of the model up to the change in the wages. Specifically, the change in the world's input-output structure to changes in frictions and productivities is given by the following equation (see online Appendix A for the derivation):

$$\Gamma = \mathcal{F}\left(\theta,\beta,\gamma\right)A + \mathcal{H}\left(\theta,\beta,\gamma\right)\tau + \mathcal{O}\left(\theta,\beta,\gamma\right)\omega, \tag{8}$$

where Γ, A, τ, and ω are vectors that contain the log changes in expenditure shares, productivities, frictions, and wages, respectively. The elasticities $\mathcal{F}\left(\theta,\beta,\gamma\right)$, $\mathcal{H}\left(\theta,\beta,\gamma\right)$, and $\mathcal{O}\left(\theta,\beta,\gamma\right)$ are matrices that depend on the elasticity θ, the share of value added in gross output β across all countries and sectors, and all expenditure shares γ. These matrices provide the direct effects of frictions and productivities on the input-output shares as well as the indirect effects through changes in prices.

To reduce the notational burden and discuss our main insight from the input-output elasticity, we derive below this elasticity under some simplifying assumptions. Specifically, we assume one country i and two sectors j, k. We normalize the wage in that country to 1 and study the elasticity of the input-output share $\gamma_{ij,ik}$ to a change in the frictions $\tau_{ij,ik}$ and $\tau_{ik,ij}$. Totally differentiating the expression for the prices and for the input-output shares, we have that the elasticities of the input-output shares with respect to frictions are given by (see online Appendix A for the derivation)

$$\frac{d\log\gamma_{ij,ik}}{d\log\tau_{ij,ik}} = -\theta\frac{1-\tilde{\gamma}_{ij,ik}}{1-\tilde{\gamma}_{ik,ij}(1-\beta_{ik})\tilde{\gamma}_{ij,ik}(1-\beta_{ij})}, \frac{d\log\gamma_{ij,ik}}{d\log\tau_{ik,ij}} = (1-\beta_{ik})\tilde{\gamma}_{ik,ij}\frac{d\log\gamma_{ij,ik}}{d\log\tau_{ij,ik}}, \tag{9}$$

where $\tilde{\gamma}_{ij,ik} \equiv \frac{\gamma_{ij,ik}}{1-\gamma_{ij,ik}(1-\beta_{ij})}$.

Similarly, the elasticities of the input-output shares with respect to sectoral TFPs are given by

$$\frac{d\log\gamma_{ij,ik}}{d\log A_{ij}} = \theta\frac{\tilde{\gamma}_{ij,ij}\left(\tilde{\gamma}_{ik,ij}\left(1-\beta_{ik}\right)-1\right)}{1-\tilde{\gamma}_{ik,ij}\left(1-\beta_{ik}\right)\tilde{\gamma}_{ij,ik}\left(1-\beta_{ij}\right)}, \frac{d\log\gamma_{ij,ik}}{d\log A_{ik}} \tag{10}$$

$$= \theta\beta_{ij}\frac{\tilde{\gamma}_{ij,ij}+(1-\beta_{ik})\tilde{\gamma}_{ik,ik}\tilde{\gamma}_{ij,ij}}{1-\tilde{\gamma}_{ik,ij}\left(1-\beta_{ik}\right)\tilde{\gamma}_{ij,ik}\left(1-\beta_{ij}\right)}.$$

The main insight from these equations is that the input-output elasticities with respect to changes in frictions and productivities are not constant or mechanically driven by the elasticity θ, but they depend on the whole production network. In other words, computing the impact of a change in frictions anywhere in the world on a given input-output share requires keeping track of the whole world's input-output matrix. Equally important, equations (9) and (10) show that we can compute the elasticities without knowing the level of frictions or TFPs. This does not mean that frictions do not matter for the elasticities; it means that conditioning on the input-output shares, which contain information of the frictions, we can evaluate how changes in frictions affect the world economy.

With this set of theoretical results, we proceed in the next section to compute the world's input-output elasticities to changes in frictions, to identify the actual growth rate in frictions over time, and to study the impact of these actual changes in frictions on the world's input-output structure. We start the next section by describing the data needed for our quantitative exercises. We then proceed to compute the world's input-output elasticities to changes in frictions. We first study how the input-output structure in a given country changes with a change in internal frictions. We also compute the effect of a change in internal frictions in a given country on the input-output structure of a different country. We then take a global view and study how changes in internal frictions in a given country and sector impact the world's GDP, which sectors and countries have a larger impact on the world's GDP, and how relevant internal versus external frictions are for the world's economy.

Before turning to the quantitative analysis, we close the model by imposing the market clearing condition given by

$$w_i L_i = \sum_{k=1}^{J}\sum_{n=1}^{N}\frac{\beta_{nk}}{1-\beta_{nk}}\gamma_{nk,ij}X_{nk}. \tag{11}$$

The equilibrium of this economy is therefore defined by equations (2), (3), (4), and (11).

II. Quantitative Analysis

A. *Matching the World Input-Output Matrix*

The data used in the quantitative analysis are the Input-Output Tables from the 2013 release of the World Input-Output Database (Timmer et al. 2015). The WIOD database traces the flow of goods and services across 35 industries classified according to the NACE classification system, 40 countries, and a constructed rest of the world, over the period 1995–2011. These data are integrated into a world input-output table, which also provides gross output and value added for each sector and country. In online Appendix B, we provide the list of the sectors and the countries.

The flow of goods and services includes domestic transactions of intermediate goods, that is, flows across industries in a given country, as well as cross-sector and cross-country flows. Using these flows, we are able to directly determine the bilateral expenditure shares $\gamma_{ij,nk}$ across all countries and sectors. The WIOD database also contains final expenditure across sectors and countries that we use to construct α_{ij}. In doing so, we leave out changes in inventories from the calculations. The shares of value added across sectors and countries, β_{ij}, are constructed using value added and gross output data for each sector and country. Finally, as described above, trade models deliver a gravity equation that maps into our expenditure share equation (5) for the case of cross-country and within-sector transactions, and hence θ can have the interpretation of a trade elasticity. In consequence, we use a value that is commonly used in the literature, $\theta = 4$ (e.g., Simonovska and Waugh 2014). For the case of σ, there is not an analogous reference value in the literature, and therefore, we consider values in the range from 2 to 6. In the main text, we present results with the middle value of 4, and in online Appendix E.1, we show how results are affected by different values σ and θ.

Finally, we emphasize that although the WIOD is the most complete available database on input-output transactions across sectors and countries, it is subject to some limitations. In particular, WIOD data construction relies on the assumption that industries use an import of materials proportional to their total use, the so-called "proportionality assumption." Also, the WIOD uses input-output data from input-output tables that are not produced annually, and therefore part of the input-output data is imputed with annual trade and macroeconomic data.[9]

Figure 1 displays the heatmap of the world input-output table for the year 2011. Specifically, it shows the bilateral expenditure shares across all sectors and countries in the world, where the y-axis (rows) presents the buyer unit and the x-axis (columns) shows the seller unit. The colors in the figure represent different percentiles that are labeled on the right-hand side of the figure, and the observations are ordered first by country and then by sector. For instance, the eightieth percentile corresponds to an expenditure share of 0.0049; that is, the buyer unit is spending 0.0049 percent of its total expenditure on goods from that specific seller unit. Since observations are ordered first by country and then by sector, the first red square visualized in the figure displays the Australian domestic input-output coefficients, that is, expenditure share of each Australian sector on goods from every other industry in Australia.

We want to highlight two relevant features from the world input-output table. First, the diagonal is strong; that is, the red squares along the diagonal of the figures mean that the domestic input-output transactions tend to be stronger than the cross-country transactions. However, the importance of domestic input-output linkages varies across countries. For instance, we can see from the figure that in more open economies such as Luxembourg, a greater number of domestic input-output shares fall below the eightieth percentile than in other countries, which indicates that domestic transactions are relatively less important in Luxembourg. Second, the world is very interconnected, with countries such as China, the United States, and Germany playing a role of the important suppliers of inputs for all countries in the

[9] See, e.g., De Gortari (2019) for a discussion of the quantitative implications of the proportionality assumption in the WIOD. An alternative world's input-output table is Eora, which traces input-output transactions for 26 sectors and 190 countries, but which is constructed with even more data imputations than WIOD due to the lack of data for many small countries in the sample.

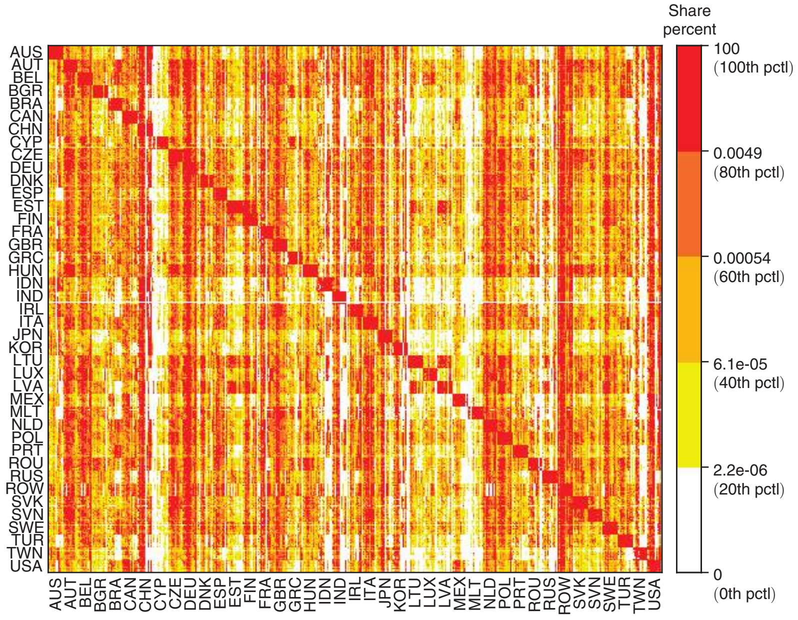

Figure 1. Global Expenditure Shares across Sectors and Countries in 2011

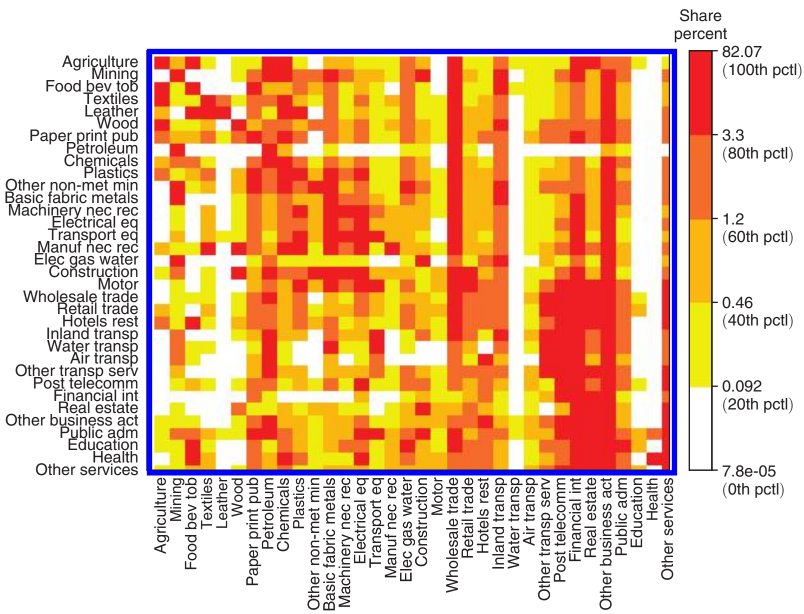

Figure 2. US Expenditure Shares across Sectors and Countries in 2011

world. Later, we discuss further how these features shape the elasticities of GDP and expenditure shares with respect to changes in frictions.

In Figure 2 we reproduce the input-output for the US economy presented as a heat-map. The y-axis (rows) shows the buyer sectors from each seller sector in the x-axis (columns). In the figure, for a given seller industry, we aggregated US purchases

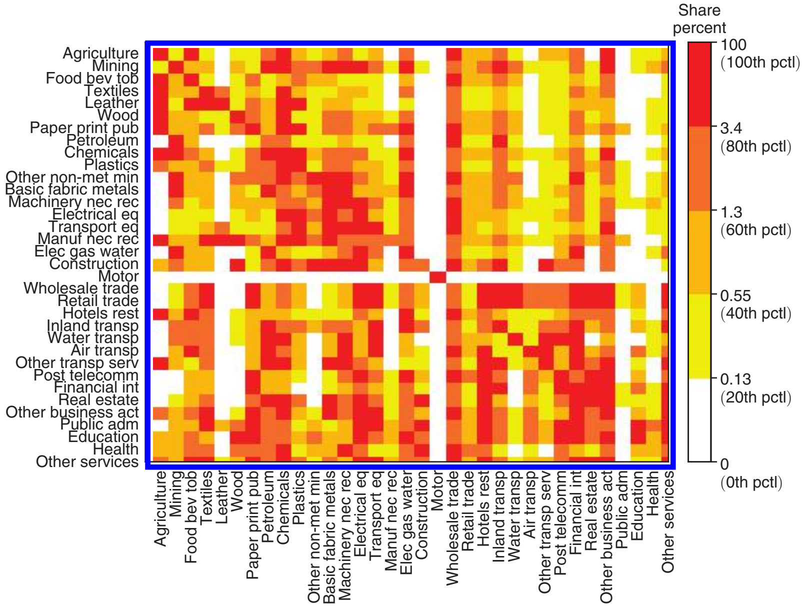

Figure 3. China's Expenditure Shares across Sectors and Countries in 2011

from all countries in the world in that industry. Similar to the previous figure, the colors represent different percentiles that are labeled on the right-hand side of the figure. For instance, the eightieth percentile in the figure corresponds to a US sector that spends at least 3.3 percent of their total expenditure on goods from a given seller, including purchase from the United States, and from all other countries in the world.

We observe from the figure that the diagonal is strong; that is, a sector tends to buy more materials from itself rather than other sectors. Still, the interconnection across sectors is also relevant. In particular, some service sectors such as finance and business activities are an important source of intermediate inputs to other sectors as well as some manufacturing sectors such as petroleum and paper. The same features characterize the input-output table of China displayed in Figure 3.

We now compute the elasticities of these input-output tables in these countries to changes in internal frictions, as well as the cross-country elasticities where frictions in other countries change.

B. *Input-Output and World's GDP Elasticities*

As discussed in Section ID, in our model changes in frictions impact wages and prices in the whole world economy, and the input-output shares across all sectors and all countries may change as a result. Given this, the world's input-output structure is endogenous to changes in frictions. Therefore, armed with our model and the data from the WIOD, we emphasize this point by computing the elasticity of the input-output shares to changes in internal frictions.

We first focus on the United States and China's input-output structure and compute how their input-output structure changes with respect to changes in their own internal

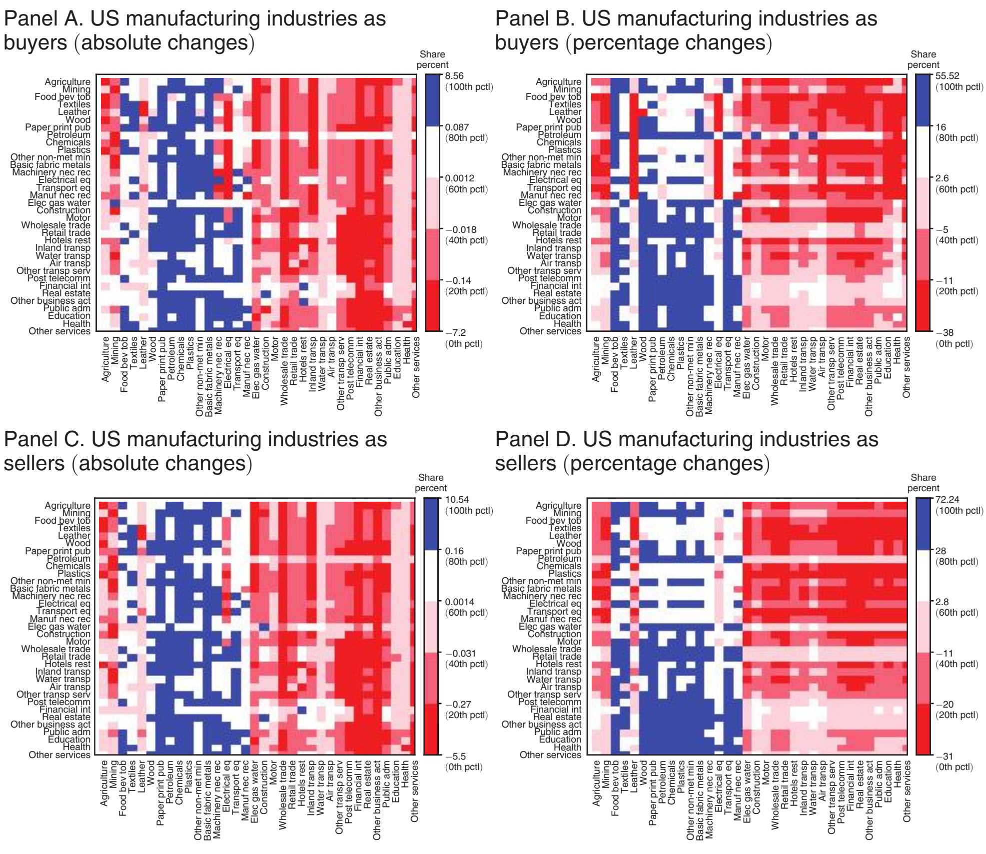

Figure 4. Change in US Expenditure Shares to US Internal Frictions in Manufacturing

frictions. We then compute the effects on the US input-output structure from changes in internal frictions in China—the cross-elasticity of China's internal frictions on the United States. We then take a global view on the impact of internal frictions on the world's input-output structure.

We start by computing how the US input-output structure would change with respect to a 10 percent decline in internal (within the United States) frictions in the manufacturing industries (namely, $\hat{\tau}_{ij,ik} = 0.9$ for all j and k). The results are displayed in Figure 4.

The upper two panels show the effects of the decline in the frictions of selling goods to manufacturing industries from any industry. The lower two panels show the effects of the decline in frictions of buying goods from the manufacturing industries by any industry. We show the change in expenditure shares to changes in internal frictions in absolute terms on the left panels, and in percent changes on the right panels. We can see from the figure how the US input-output table is impacted by changes in frictions in the manufacturing industries. In particular, we observe that manufacturing sectors buy more from other manufacturing sectors. Since it is cheaper for manufacturing industries to buy intermediate inputs from everywhere, they will buy proportionally more from the manufacturing industries because those

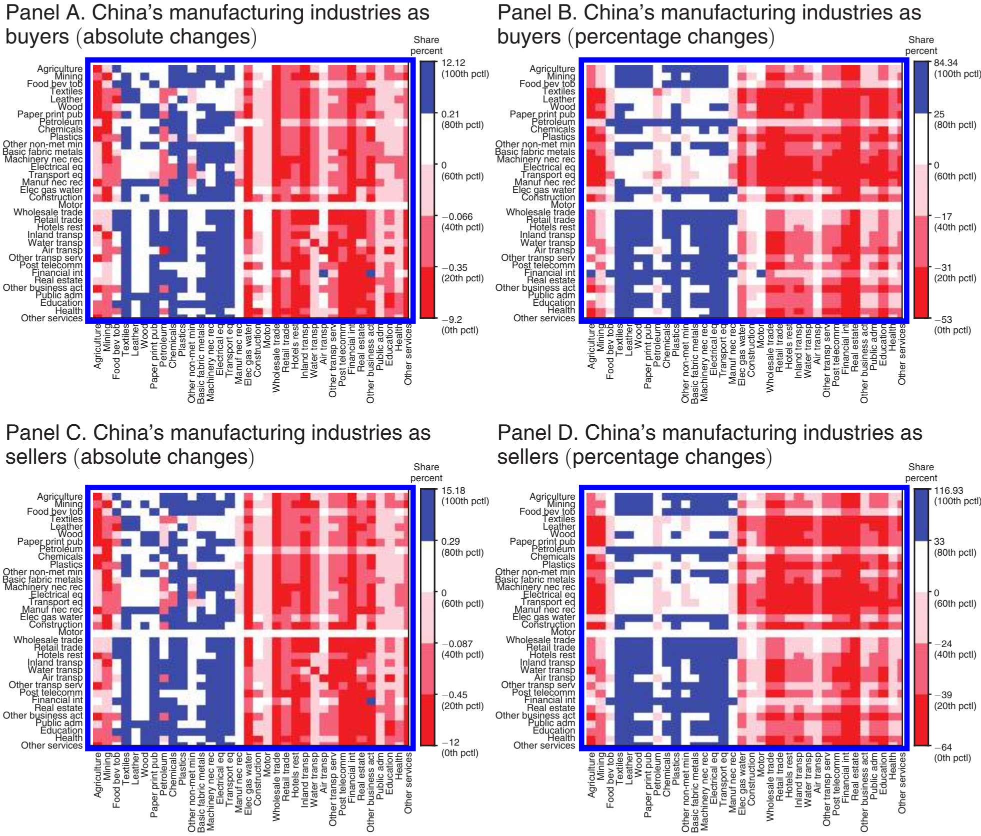

FIGURE 5. CHANGE IN CHINA'S EXPENDITURE SHARES TO CHINA'S INTERNAL FRICTIONS IN MANUFACTURING

industries experience a larger decline in the price index. In the lower panels, we observe that all sectors, and especially nonmanufacturing industries, substitute inputs from nonmanufacturing industries for manufacturing inputs, as the latter are now a cheaper source of inputs after the decline in frictions. These two findings are in line with the effects discussed in Section ID.

In Figure 5, we perform the same exercise but for a different economy, China, as a way of confirming whether the findings for the United States hold for another economy with a different input-output structure. The four panels in Figure 5 follow the same structure as in Figure 4. In a nutshell, we can see qualitatively similar effects of the changes in internal frictions in China on the Chinese input-output structure. The upper panels show that manufacturing industries tend to buy more from manufacturing sectors, and the lower panels show that manufacturing industries increase their importance as suppliers for the rest of the economy.

These findings confirm a common pattern across countries, in line with the predictions of our closed-form elasticities. However, we emphasize the fact that the input-output structure of the US economy is different from the Chinese one, and therefore, the effects of the changes in frictions at the more disaggregate level are different in these two economies. The sectors that increase more the purchases of manufacturing in the United States are Leather and Textiles, while in China, the sectors that experience the largest increase in manufacturing purchases are Transportation Equipment and Metals. Overall, these exercises show how our model and the derived elasticities emphasize these heterogeneous input-output effects from changes in frictions across countries.

We now compute the cross-country effects of changes in internal frictions in the manufacturing sectors. Specifically, we compute the change in the US input-output shares from a 10 percent reduction in the internal frictions in China. Figure 6 shows the results.

Similar to the previous Figures 4 and 5, the upper panels show the effects of changes in manufacturing frictions as buyers of goods from any industries, and the lower panels show the change in internal frictions from selling from the manufacturing industries. As in the previous figures, the left panels show absolute changes in expenditure shares, and the right panels show percent changes in expenditure shares.

Turning to the results, Figure 6 shows two relevant facts. First, the US economy purchases proportionally more inputs from the manufacturing industries, and also manufacturing industries increase their importance as suppliers for the rest of the US economy, especially in industries such as Textiles, Leather, Plastics, Machinery, Electrical Equipment, and Transport Equipment. This highlights the fact that the Chinese manufacturing is more connected to the US manufacturing sectors than to other industries.

These results highlight how complex the input-output relationships within countries and across countries are and given this, how important it is to account the endogenous changes in them as a result of changes in frictions anywhere in the world.

We now take a global perspective of the input-output shares and compute the elasticity of the world's expenditure shares and elasticity of the world's real GDP to changes in internal frictions. We also compute the elasticity of the world's GDP with respect to external frictions and discuss the relative importance of the internal versus external frictions.

In Figure 7, we start with a similar computation to the one performed previously, but taking a view at the whole world's input-output structure. To do so, we compute the change in expenditure shares in all countries and sectors in the world from a 10 percent reduction in internal frictions all over the world. The main conclusion we get from the figure is that changing internal frictions at the same time has dramatic change in the world's input-output structure, which reinforces our previous findings. From the figure, we can see that changes in domestic input-output transactions are important, but we also see significant changes in the whole world's input-output structure. Also, countries that are more connected to the global economy, namely, source more inputs from abroad, experience a larger increase in the share of inputs purchased from other countries. This point is better illustrated in the right-hand panel by looking at the rows; we can see that more open economies such as Belgium, Luxembourg, Ireland, and Taiwan become even more connected to the world as a consequence of having access to cheaper materials, relative to less connected countries such as Russia that mostly increase the domestic expenditure shares.

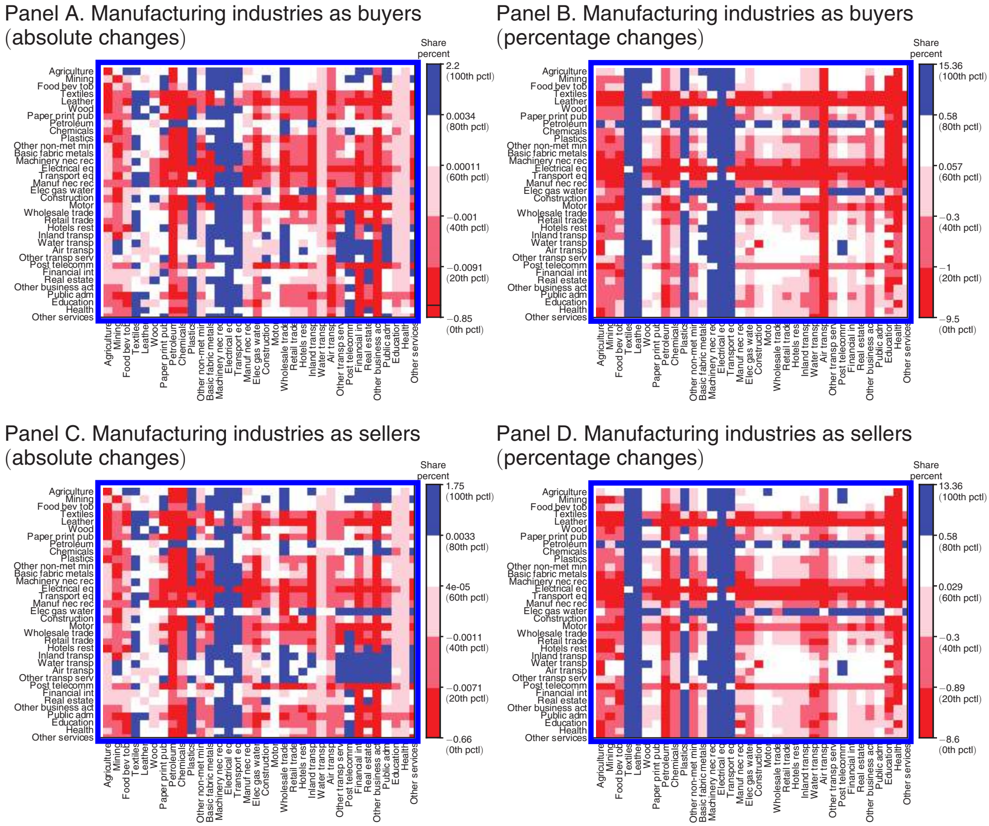

Figure 6. Change in US Expenditure Shares to China's Internal Frictions in Manufacturing

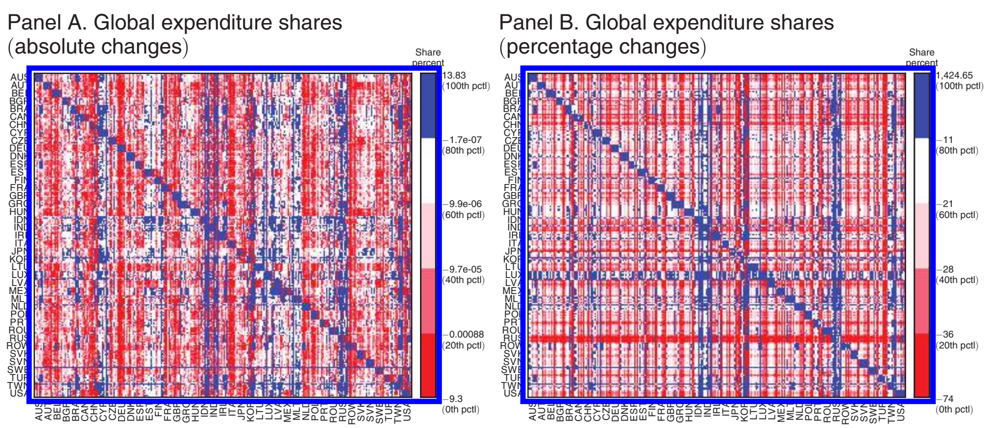

Figure 7. Change in Global Expenditure Shares to Internal Frictions in Manufacturing

In Figure 8, we compute the world's real GDP elasticities with respect to changes in internal frictions in each country. Specifically, each unit in the figure shows the percent change in the world's real GDP from a 1 percent reduction in frictions in a given industry and country of buying goods from all industries in that country.

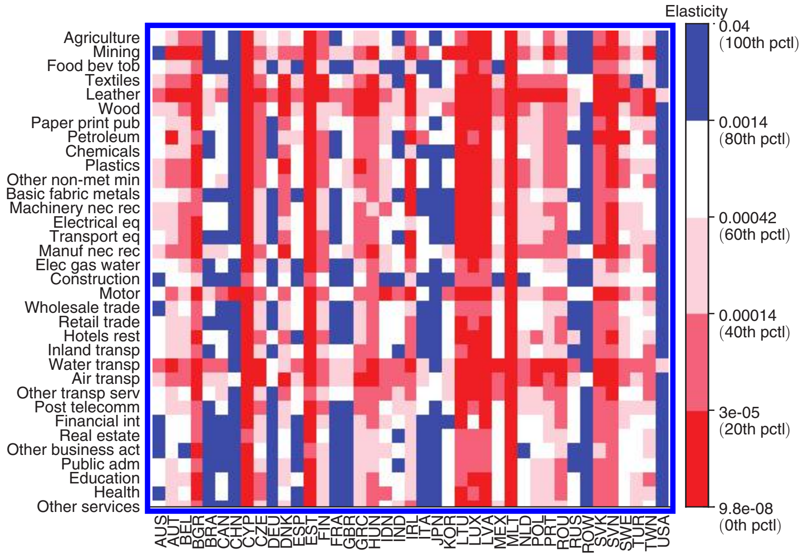

Figure 8. World's Real GDP Elasticity to Changes in Internal Frictions

The change in the world's real GDP is computed by aggregating the changes in real wages across all countries using each country's GDP as weights. As in the previous figures, each color represents a given percentile. For instance, the blue cells correspond to the country-sectors whose changes in internal frictions would have a larger impact in the aggregate world's economy. This is the case of most of the sectors in the United States and China as well as some important sectors such as real estate, finance, business activities, and public administration in some developed countries such as Germany, France, Italy, and Japan. Overall, the elasticity of the world's real GDP is affected by both the size of the industry and how interconnected is a given industry in a given country with the rest of the economy, and with the rest of the world, and as a result, the bottom line of this exercise is to shed light on how quantitatively significant the impact on the world's economy as a whole would be to changes in internal frictions in specific sectors and countries.

Even more starkly, the importance of the internal frictions can be seen in Figure 9. Here, we rank the top 60 elasticities of the world's GDP to a sector in a given country. As an example of the importance of internal frictions, the internal elasticity—that of China's construction sector—has about three-fourths the magnitude of the elasticity of the world's GDP to all of the external frictions in the United States computed below. More broadly, this graph shows the importance of the frictions of individual sectors on the world economy.

Of course, the elasticity of the world's GDP to changes in internal frictions in a given sector can be large because the share of the sector in the world's GDP is large or because the internal friction has a large impact in the global economy as a result of the industry and country interconnections. Therefore, we also decompose these elasticities into the contribution of the own sector that experiences the change in frictions; the contribution of the domestic production network, namely, the impact on other sectors in the domestic economy; and the contribution of

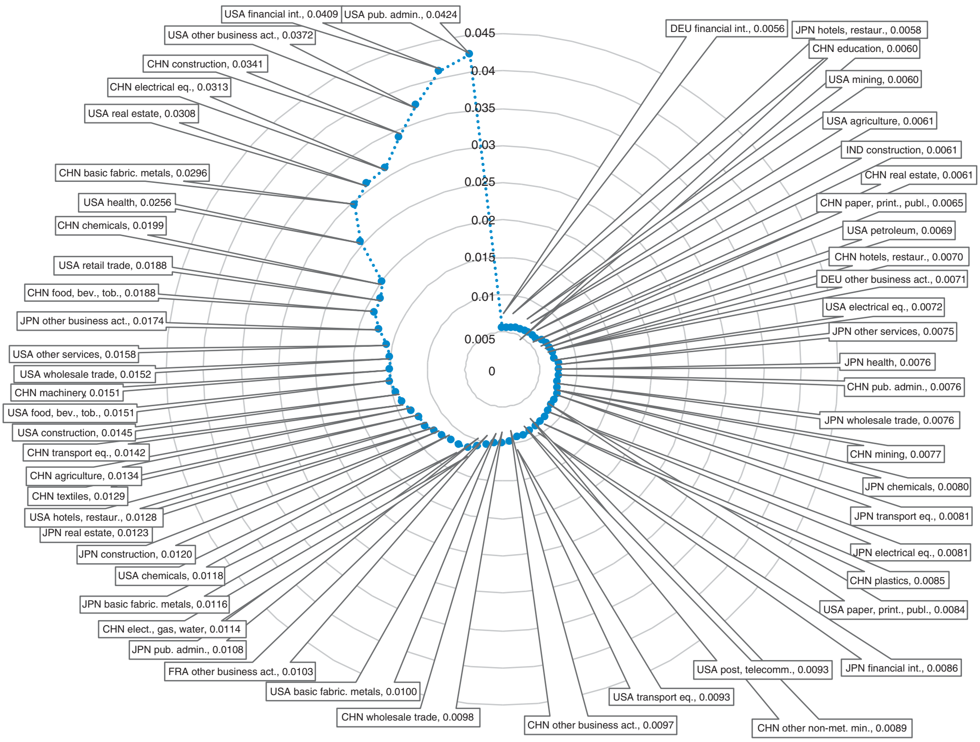

Figure 9. World's Real GDP Elasticity to Changes in Internal Frictions (*top 60 markets*)

the external network, namely, the effects of changes in GDP in other countries. In online Appendix E.3, we provide the formula to perform this decomposition.

We find that on average for all the computed elasticities in Figure 9, the own-sector contribution explains about 52.4 percent of the computed world's GDP elasticities to changes in internal frictions, the domestic network explains 48.4 percent, and the external network explains about −0.9 percent. This average, however, masks great heterogeneity across individual country/sector units. For example, in some sectors, like construction in China, most of the world's GDP elasticity is explained by the own-sector contribution, about 85 percent, while the domestic network explains 16 percent and the external network contributes by only 0.8 percent. But other important sectors for the world's economy, such as electrical equipment in China, show a different picture; the own sector contributes by much less, about 25 percent, while the domestic and external networks are much more important, contributing by about 55 percent and 20 percent, respectively. Overall, the own-sector contributions range between 18.5 percent (Plastics in China) and 95.8 percent (Health in the United States), the contribution of the domestic network ranges between 7.9 percent (Health in Japan) and 81.1 percent (Paper, Print, and Publishing in China), and the contribution of the external network fluctuates between −11.3 percent (Financial Intermediation in Germany) and 19.9 percent (Electrical Equipment in China). Examples of other sectors where the contribution of the external network is important are Electrical Equipment in Japan (13.1 percent), Transport Equipment in Japan (17 percent), and Textiles in China (10.4 percent). Online Appendix E.3 presents a ranking of the country/sector

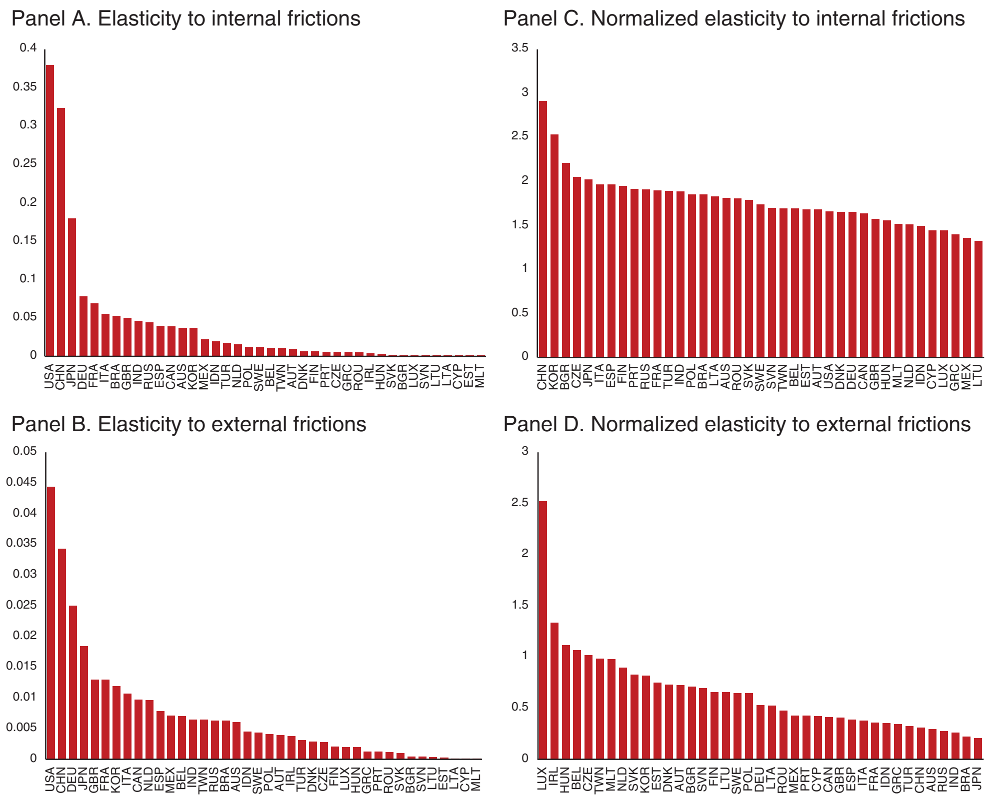

Figure 10. World's Real GDP Elasticity to Internal versus External Frictions (*2011*)

according to the importance of the own-sector contribution, domestic network, and external network to the computed elasticities of the world's GDP.

In Figure 10, we compute the world's real GDP elasticity to changes in internal frictions in a given country in the upper panels, and we then compare them with the world's real GDP elasticity to changes in external frictions in the lower panels. Comparing the elasticities with respect to internal versus external frictions, our main result is that the elasticity with respect to the internal frictions is an order of magnitude larger than that of external frictions.

This finding can be connected to our findings in the previous section that domestic input-output relations tend to be more important than cross-country input-output relations. This different magnitude between internal versus external elasticities also sheds light on the potential impact of changes in domestic versus external policy-related frictions. In panel A, we can see that the largest elasticity is that of the United States at 0.38, followed by China (0.32), Japan (0.18), and Germany (0.08). Panel B presents the calculations for the elasticity of the world's GDP to external frictions. The largest elasticity is that of the United States at 0.044, followed by China (0.034), Germany (0.025), and Japan (0.018).

Similar to the discussion above, one might think that the world's GDP elasticity to changes in internal frictions is mechanically large in countries that have a larger share in global GDP. To control for the size effect, we also compute these elasticities normalized by the share of each country in the world's GDP (panels C and D). These normalized elasticities are interpreted as the elasticity of the world's GDP of an equivalent world's size shock to internal frictions in each country. This way, if two countries have exactly the same input-output network, and they only differ in size, they will have the same normalized elasticity. Therefore, differences in the normalized elasticities reflect the heterogeneity in the production network across countries but not the differences in the country size. As expected, more open and connected economies such as China become even more relevant for the world when we normalize by the country size relative to, for instance, similarly large countries but with less external trade, like the United States. Importantly, the normalized elasticities still show that the elasticities of internal frictions are an order of magnitude larger than the elasticities of external frictions.

In addition, we explore how these computed elasticities change if they are computed at the initial year 1995 instead of 2011. Figure 11 presents the results. Looking at the elasticity to internal frictions we find, as expected, that China is much less relevant for the world's economy (elasticity of 0.063 versus an elasticity of 0.32 in the year 2011). This is one of the key aspects that we emphasize in the paper, the fact that these elasticities are not constant but depend on the whole global input-output structure, as we showed in Section ID. Still, relative to its size, we find that China has the largest normalized elasticity, although the magnitude of the elasticity is smaller than the one in 2011. In online Appendix E.2, we compute these elasticities for other years, namely for the years 2000 and 2005. In line with the previous discussion, the elasticity of the world's GDP to changes in internal frictions in China is 0.095 for the year 2000 and increased to 0.137 in the year 2005.

C. *Frictions and TFP*

In this section, we use the sufficient statistics derived in Section I to compute the evolution of internal frictions and TFPs for the period of study. Our principal finding is a significant heterogeneity in the growth rate of the frictions and their distribution across countries. We conclude with the computation of the change in global input-output shares and the world's real GDP elasticity to the actual changes in domestic frictions over the period 1995–2011.

Internal Frictions.—Turning to the analysis of the internal frictions, Figure 12 shows the distribution of the annual rate of growth of internal frictions for the world and for selected countries. This graph shows several notable features. First, there is large heterogeneity in terms of the growth rate of frictions across sectors. For each country, there are sectors in which the frictions grew and in which frictions decreased. Second, the heterogeneity differs across countries. The United States and Japan have relatively small dispersion compared to Europe, and all of these countries have much smaller dispersion compared to China.[10]

[10] In online Appendix E.1, we show how our computed changes in frictions are shaped with different values of the elasticities σ and θ. We can see in our formulas to identify internal frictions derived in Proposition 1 that the magnitudes of θ and σ impact the dispersion of the changes in internal frictions.

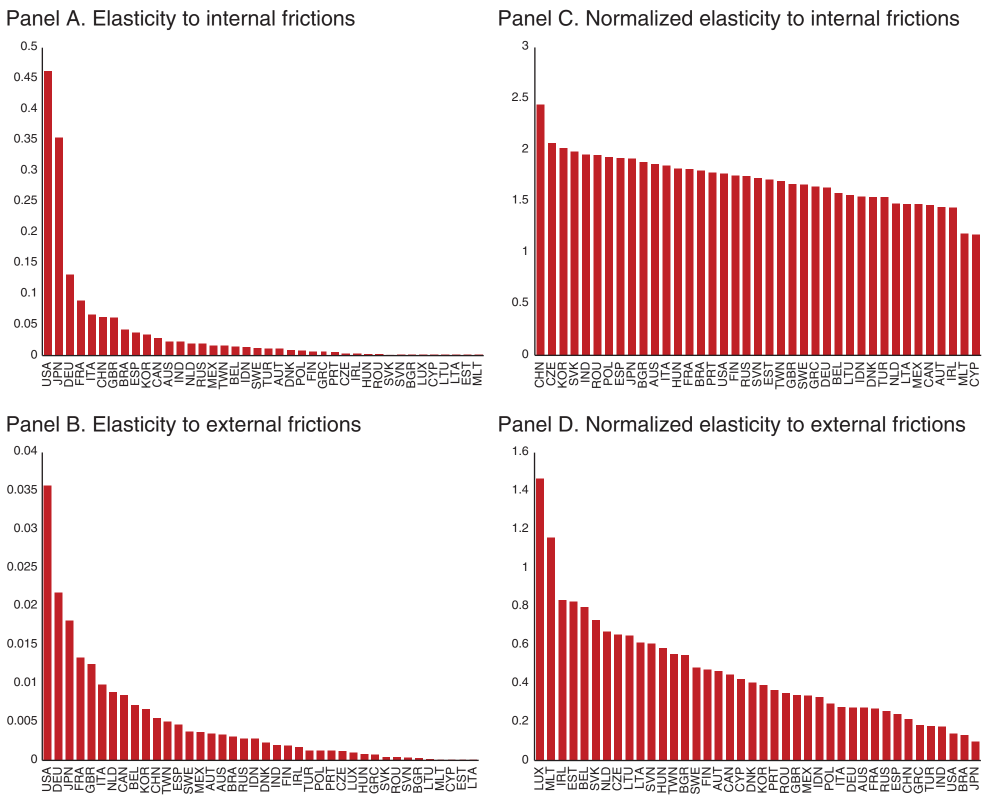

FIGURE 11. WORLD'S REAL GDP ELASTICITY TO INTERNAL VERSUS EXTERNAL FRICTIONS (*1995*)

The main bottom line of these histograms is that, to a greater or lesser extent, there is heterogeneity in the changes in internal frictions in all countries, and some sectors have increased friction and others reduced friction in some countries relative to others. Therefore, aggregate measures of relative frictions across countries can give only a partial view of the degree of frictions across countries since they hide this high heterogeneity at the more disaggregate level.[11]

TFP.—We now turn to our TFP calculations. As described in Section I, with our sufficient statistics, we can compute TFPs relative to a reference sector in each country. Therefore, in all calculations below, we present our TFP calculations relative to the agriculture sector. We start by describing the change in sectoral TFP in the world over the period 1995–2011.

[11] As a robustness exercise we check that the distribution of the annual growth in internal frictions for alternative sample periods, namely 1996–2011 and 1995–2010, looks very similar to the one in Figure 12. The correlation between the annual growth in internal frictions for the period 1995–2010 and for the period 1995–2011 is 0.99, and the correlation between the periods 1995–2011 and 1996–2011 is 0.95. Online Appendix E.4 shows the distribution of the changes in internal frictions for these different sample periods. We also computed the persistence of the computed in internal frictions. Specifically, we computed the autocorrelation coefficient of internal frictions and find that the average and median first-lag autocorrelation is 0.6 and the second-lag is 0.36, which indicate that our computed frictions are not random.

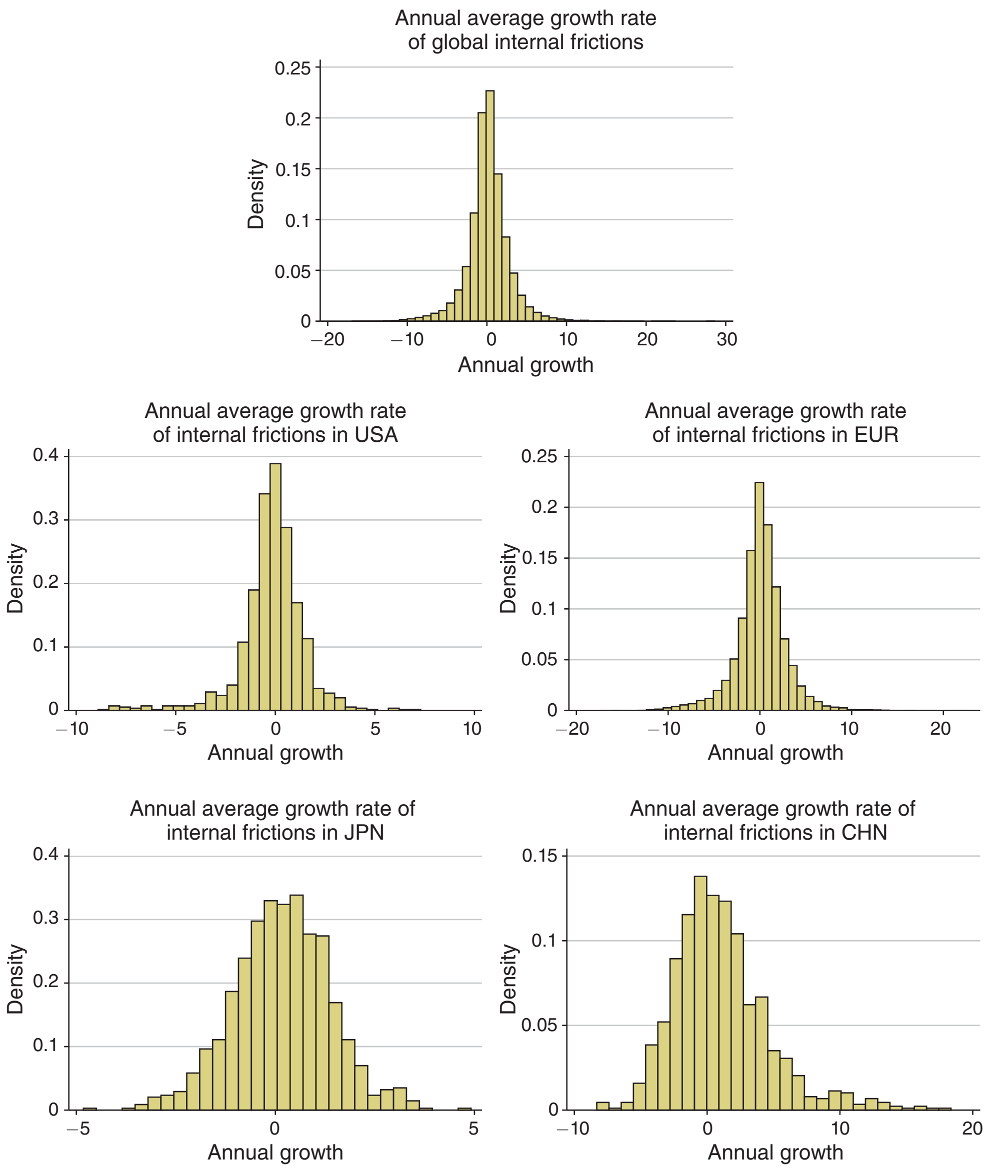

Figure 12. Distribution of Changes in Internal Frictions in Selected Countries

The upper panel in Figure 13 shows the evolution of the TFP in the manufacturing sector and the service sector, using gross output weights to aggregate TFP across industries and countries.[12] The lower panels show the annual growth in TFP in the world across different manufacturing and nonmanufacturing sectors. A clear fact from the figure is the higher growth rate in the service sectors than in

[12] Basu and Fernald (2001) and Basu, Fernald, and Kimball (2006) show how to construct a measure of aggregate TFP in environments different from ours.

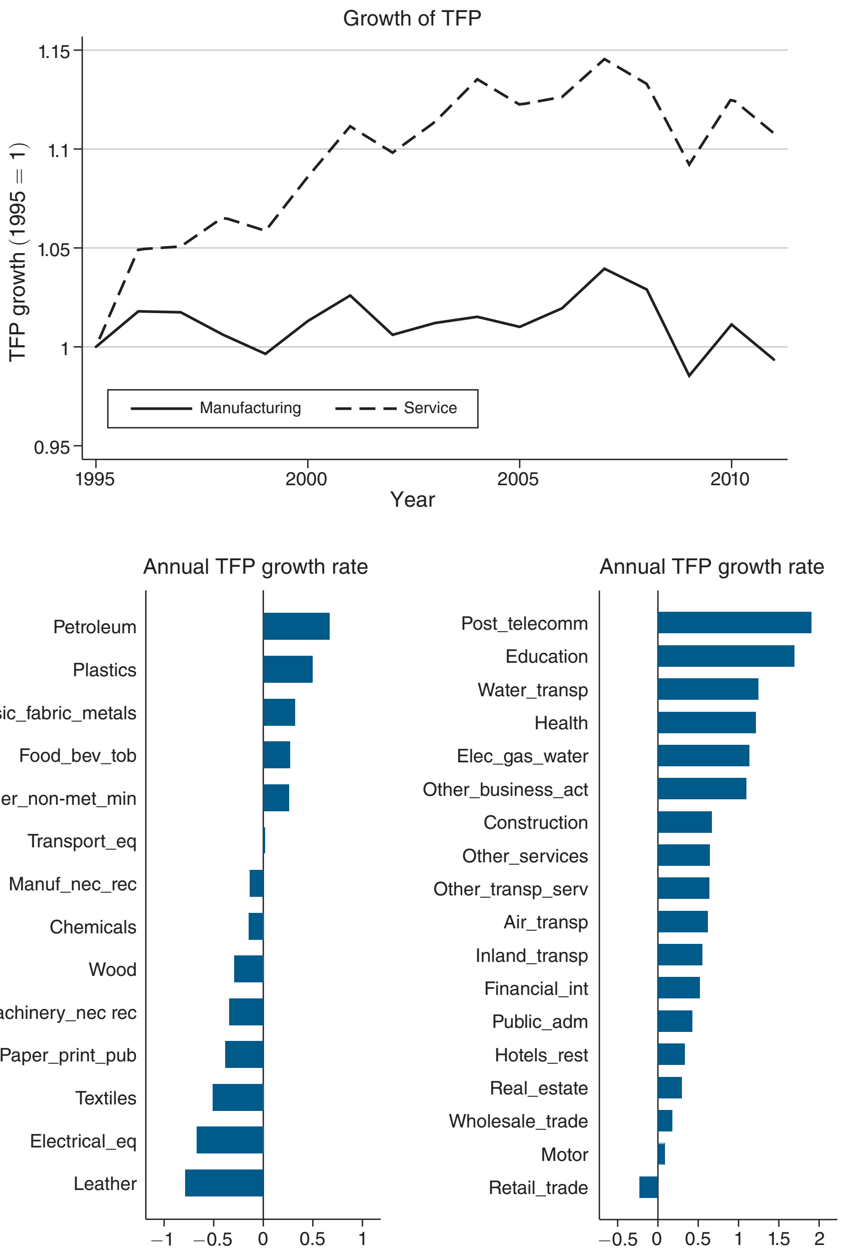

Figure 13. World's TFP Annual Growth Rate

the manufacturing sectors. Among service sectors, we find that telecommunications, education, and water transport experienced the highest growth rate in TFP in the world, while retail sales slightly contracted. In the manufacturing industries, petroleum, plastics, and metals are the sectors with the highest growth rate.

As a way of validating our TFP measure, in Figure 14, we compare our constructed TFP series for the United States, where we recover the aggregate TFP

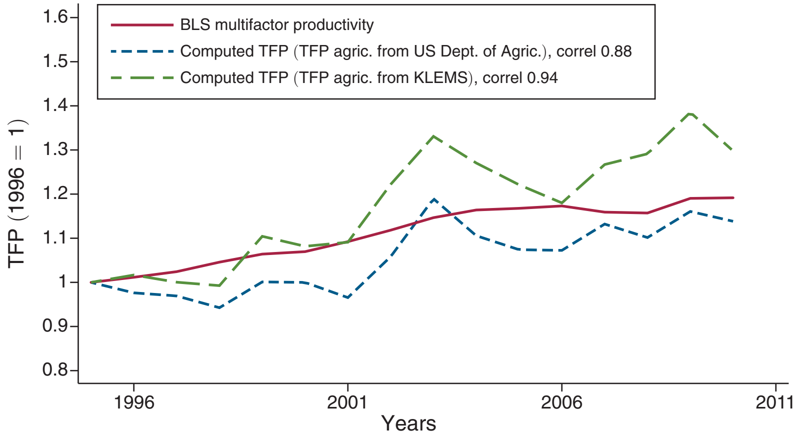

Figure 14. US Aggregate TFP

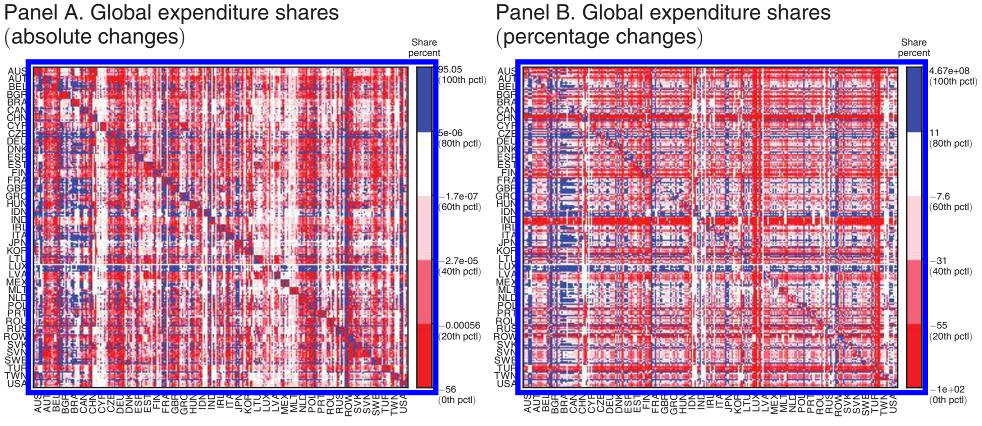

Figure 15. Change in Global Expenditure Shares to Actual Changes in Internal Frictions

by using TFP estimates from the agricultural sector from the US Department of Agriculture and from EU-KLEMS, with the BLS multifactor productivity. We see that our model-implied aggregate TFP series is in line with that from the BLS, although it is somehow more volatile. Overall, the correlation between both is very high.

Effects of Actual Changes in Internal Frictions.—In this section, we combine the elasticities of the input-output shares and the world's GDP with respect to changes in internal frictions, and our computed internal frictions using the sufficient statistics derived in Section I. We then compute the change in the input-output shares across all sectors and countries in the world and the world's GDP elasticities to the actual changes in frictions over the period 1995–2011.

We start with Figure 15, which shows the change (absolute and percent) in global expenditure shares with respect to the actual changes in internal frictions. In other words, the figure shows how the world's input-output structure would have

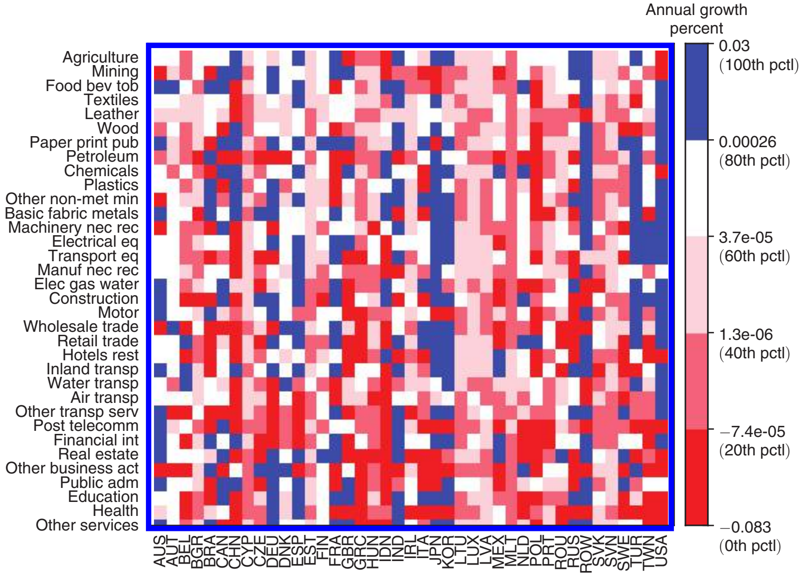

Figure 16. Growth in World's GDP with Respect to Actual Changes in Internal Frictions

changed if internal frictions were back to their 1995 level. As we have emphasized above, the world input-output structure shows complex interconnections across sectors and countries, and these interconnections respond endogenously to changes in frictions. As a result, we see how the actual changes in frictions have changed the world's input-output structure near all over the units. We can see more significant changes in the domestic input-output relationships; that is, the stronger diagonal of the matrix means that domestic input-output relationships would have been more important today if frictions would have stayed at the level of 1995. We also see quite heterogeneous effects across countries, reinforcing our view on the importance of seeing the world as a single input-output structure with complex interrelations. Notably, the right panel highlights more clearly how China would have been less connected to the rest of the world as a supplier and seller.[13]

Finally, Figure 16 displays the change in the world's GDP with respect to the actual changes in internal frictions. We compute the change in the world's GDP by aggregating the change in real wages across countries using each country's GDP as weights. The figure shows that the growth rate in the world's GDP to a change in local friction has been very heterogeneous across different sectors and countries in the world. This finding is consistent with the heterogeneity in the growth rate in internal frictions discussed above and also with the fact that some sectors have greater friction and others less friction in some countries relative to others. For

[13] The very large percentage changes at the top percentile on the right panel correspond in general to cases with a very small (close to zero) initial input-output share that experienced significant changes in frictions over 1995–2011. Examples of these outliers are purchases from the metal sector by a number of manufacturing industries in Malta, purchases from textiles by the finance and transport service industries in Cyprus, and purchases from mining by construction in India.

instance, lower frictions in China in sectors such as education, health, construction, and electrical equipment contributed to a positive global GDP growth, while sectors such as plastics and metals had a negative impact on world's GDP; namely, the world's real GDP would have been higher with the frictions in these sectors staying constant at their 1995 level.

III. The Role of Internal Frictions during the Great Recession

In this section we apply our model and methodology to study the role of internal frictions in the changes in external and internal trade during the Great Recession of 2007–2009.

The large decline in international trade relative to production during the Great Recession as well as the relative contribution of different frictions have been studied in recent literature. Among others, Levchenko, Lewis, and Tesar (2010) find a disproportionally larger collapse in international trade than in domestic activity, pointing to an increase in trade wedges in the United States; Alessandria, Kaboski, and Midrigan (2013) show that inventories played a significant role on the US import collapse during the global financial crisis; and Eaton et al. (2016) explore the contribution of different shocks to the trade collapse.

Our framework provides new results to this literature in two main dimensions. First, we document the change in external trade and (not relative to) internal trade during the Great Recession, different from the literature that has mostly looked at the collapse in international trade relative to production. Second, with our framework, we can quantify the role of internal frictions in the observed change in internal and external trade during this period. This is not possible in workhorse trade models with exogenous input-output linkages or in closed economy models that do not take into account how countries and sectors within and across countries are interrelated. In our framework, the fact that internal trade can be impacted by changes in internal frictions, which in turn can affect external trade since sectors and countries are interconnected through the endogenous world's input-output structure, allows us to study the role of internal frictions on internal trade and external trade during the Great Recession. In fact, how internal frictions can potentially impact the whole input-output structure (domestic and international transactions) is one main message that we highlighted in Section IIB.

We start by documenting the observed changes in external and internal trade during the period 2007–2009. To do so, we divide all transactions into three categories. First, the export and imports of goods across countries that we label as external trade, computed as $\Delta\%\text{External Trade}_i = 100\left(\frac{\frac{1}{2}\sum_j\sum_n\sum_k\left(X_{ij,nk}^{2009} + X_{nk,ij}^{2009}\right)}{\frac{1}{2}\sum_j\sum_n\sum_k\left(X_{ij,nk}^{2007} + X_{nk,ij}^{2007}\right)} - 1\right)$. Second, the purchases and sells across industries within a country that we label as internal trade, computed as $\Delta\%\text{Internal Trade}_i = 100\left(\frac{\frac{1}{2}\left(\sum_j\sum_k\left(X_{ij,ik}^{2009} + X_{ik,ij}^{2009}\right)\right)}{\frac{1}{2}\sum_j\sum_k\left(X_{ij,ik}^{2007} + X_{ik,ij}^{2007}\right)} - 1\right)$. Third, the within-sector purchases that we label as within-sector trade, computed as $\Delta\%\text{Within-Sector Trade}_i = 100\left(\frac{X_{ij,ij}^{2009}}{X_{ij,ij}^{2007}} - 1\right)$.

Table 1—Changes in Trade during the Great Recession

	External trade observed change 2007–2009 (1)	Internal trade observed change 2007–2009 (2)	Within-sector trade observed change 2007–2009 (3)
United States	−14.57%	−8.02%	−6.15%
Europe	−15.07%	−4.63%	−3.65%
Asia	−7.48%	26.4%	24.11%
World	−12.77%	7.51%	8.33%

Notes: This table presents the observed changes in external, internal, and within-sector trade during the period 2007–2009. Column 1 shows the observed percent change in external trade over the period 2007–2009. Column 2 displays the observed percent change in internal trade over the period 2007–2009. Column 3 shows the observed percent change in within-sector trade over the period 2007–2009. Europe includes the European countries in our sample listed in online Appendix B, and Asia includes China, India, Indonesia, Korea, Japan, and Taiwan.

Table 1 shows the observed changes in external trade, internal trade, and within-sector trade over the period 2007–2009. In order to facilitate the exposition, we divided our sample of countries in four representative regions: the United States, Europe, Asia (China, India, Indonesia, Japan, Korea, and Taiwan), and the world as a whole. Online Appendix E.5 presents the observed changes in internal and external trade for all countries in our sample.

The first column in the table shows the collapse in external trade documented in previous literature. The fall in external trade in the United States and Europe was about 15 percent. The decline in external trade was almost half smaller in Asia, about 7.5 percent. For the world as a whole, external trade declined by about 13 percent.

The second and third columns report the decline in domestic sales that we decompose into internal trade (purchases across sectors) and within-sector trade. We can see a decline in internal trade that was less pronounced than the decline in external trade in the United States and Europe, about 8.0 percent and 4.6 percent, respectively. However, we observe that internal trade actually went up substantially in Asia, by about 26.5 percent, and also increased in the world as a whole during the Great Recession, by about 7.5 percent.

We now turn to study the role of internal frictions in the observed changes in internal and external trade during the Great Recession. As mentioned above, our model with endogenous input-output relationships across sectors and countries allows us to study how internal frictions impact not only the domestic transactions across sectors but also international transactions.

We do so by first computing the changes in frictions using our sufficient statistic formulas, namely using the observed changes in production and consumption shares over the period 2007–2009. We then feed into our model of the world's input-output structure the changes in internal frictions and compute the counterfactual matrix of internal and external transactions $X_{ij,nk}$. Finally, we quantify the change in external trade and internal trade explained by the change in internal frictions.

In terms of the changes in internal frictions, we find that the United Stated experienced an annual increase in internal frictions of 0.43 percent during 2007–2009, while

Table 2—Contribution of Internal Frictions during the Great Recession

	External trade: Contribution of internal frictions (1)	Internal trade: Contribution of internal frictions (2)
United States	4.48%	22.36%
Europe	14.04%	8.56%
Asia	31.71%	4.79%
World	17.64%	4.31%

Notes: This table presents the contribution of changes in internal frictions on external and internal trade during the period 2007–2009. Column 1 shows the contribution of internal frictions to the observed change in external trade, and column 2 shows the contribution of internal frictions to the observed change in internal trade. Europe includes the European countries in our sample listed in online Appendix B, and Asia includes China, India, Indonesia, Korea, Japan, and Taiwan. In the counterfactuals we trimmed the 0.5 percent of outliers.

the annual increase in Europe is 0.15 percent. Interestingly, Asia presents a different pattern. The internal frictions in Asia declined by 0.29 percent annually during this period.[14]

We find that the role that changes in internal frictions had on internal and external world trade was important but very heterogeneous across regions. Table 2 shows the contribution of the changes in internal frictions to the observed change in internal and external trade during 2007–2009. In line with the intuition developed in previous sections, in countries relatively more connected to the global economy (such as the case of Asia and Europe relative to the United States), internal frictions have a larger impact on external trade than in countries with a relatively larger share of domestic trade, like the United States.

In particular, in the United States the change in internal frictions explains about 4.5 percent of the collapse in external trade but about 22.4 percent of the decline in internal trade. In the case of Europe, internal frictions have a more significant contribution to the decline in external trade, explaining about 14 percent of it, while they contribute to about 8.6 percent of the observed decline in internal trade. In Asia, internal frictions explain about one-third of the decline in external trade and about 4.8 percent of the increase in internal trade. For the world as a whole, we find that about 17.6 percent of the collapse in external trade can be accounted by changes in internal frictions and about 4.3 percent of the increase in internal trade. Online Appendix E.5 presents the results for all countries in our sample.

With this application, we have learned about the importance of changes in internal frictions during the Great Recession. While most of the change in external trade cannot be explained by these types of frictions, we find that they do seem to be important for internal transactions (either across or within sectors). These results also show that it is useful to separately identify internal frictions from productivity differences. In addition, if we further consider that during this period technological frictions were slower-moving than actual distortions, then these results can also be interpreted as the role that distortions had in the world economy during the Great

[14] These figures represent the aggregate internal median sectoral changes in frictions across sectors using gross output shares. For the case of Europe, Asia, and the world, we aggregate countries using GDP shares.

Recession. These results open the door to other interesting research questions. For example, which distortions matter more, product market or factor market distortions? What role did margins that matter to explain the collapse in external trade, like inventories, play on the change in internal trade?

IV. Conclusion

Our paper achieves several goals. First, we argue that it is fruitful to study the world economy as one interconnected input-output table with the country-sector pair as the base unit of analysis. Second, we show that the endogeneity of the input-output table due to the CES structure of production and consumption is important. This endogeneity allows us to separately identify frictions and TFPs in the cases when the input-output relationships may differ across countries. Our finding of significant heterogeneity in frictions within and across countries implies that the analysis of the aggregate frictions at the country level may be masking the effects of the disaggregated frictions. Even more importantly, we show how to analytically compute the elasticities of frictions in a given country on the endogenous structure of the input-output relationships in that country, on other countries, and on the world's economy. We find that internal frictions play an important role in determining the structure of the economies of the individual countries and of the world economy. The elasticities of the internal frictions are an order of magnitude larger than those of the external frictions. We show how the world economy changed due to the evolution of the internal frictions in 1995–2011. We see how the world became more interconnected and how China's rise affected the world economy. Finally, we find that the role of internal frictions was relevant, but heterogeneous across countries, during the Great Recession. After all, the world economy, like the economy of a single country, can be thought of as a system of interdependent processes.

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