Distortions and the Structure of the World Economy[*]

Lorenzo Caliendo
Yale University

Fernando Parro
Johns Hopkins University

Aleh Tsyvinski
Yale University

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Abstract

We develop a model of the world economy as input-output relationships subject to distortions. The base units of our analysis are the country-sectors demanding and supplying output across and within countries. The input-output matrix is endogenous – the expenditure and consumption shares depend on prices and change with the distortions. Our first analytical result is to develop a methodology to solve the identification problem, common to the literature on misallocation in input-output relationships, of separating sectoral TFPs from the sectoral distortions. Using both the input shares and the consumption shares within the CES production and CES consumption structure we derive simple closed-form sufficient statistics for the sectoral distortions and for the sectoral TFPs. Our second analytical result is to derive a closed-form solution of the elasticities of each entry in the world input-output matrix to the distortions in a given country-sector pair – that is, the elasticity of the input-output structure of the world economy. We compute a total of more than half a million internal distortions per year and TFPs for 1,400 country-sector pairs for 1995-2011 and document significant heterogeneity of those across countries and sectors. We then calculate the whole matrix of about two million elasticities to distortions and TFPs of the input-output matrix of the world economy. We show that internal (within a given country) distortions significantly affect the structure of the economy of that country and have sizeable cross effects on the input-output matrix of other countries. We rank the impacts of the individual country-sector distortions on the world's GDP. We then show that the elasticity to changes in internal distortions is an order of magnitude larger than that of the external (across countries) distortions. Finally, we compute the change in global input-output shares and world's real GDP elasticity to the actual changes in internal distortions over the period 1995-2011.

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1   Introduction

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 distortions.

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 are determined by the sectoral distortions and TFPs and change with them. Our primary interest is in identifying the distortions or wedges in these relationships, and determining the effects of changes in the distortions on the world economy.

The paper derives two main analytical results. First, we propose a methodology to decompose distortions from sectoral TFPs. Specifically, we derive simple closed-form sufficient statistics for distortions and for sectoral TFPs as the functions of the small set of directly observable sectoral input expenditure shares and the final goods consumption shares. Prior to describing our results, it is useful to outline the difficulty that the literature encountered with regard to separating distortions from TFPs. Consider the input-output model with misallocations of Jones (2011, 2013). He argues that "There is a fundamental identification problem: we see data on observed intermediate goods shares, and we do not know how to decompose that data into distortions and differences in technologies."[1] We solve this identification problem 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, Carvalho, Ozdaglar, Tahbaz-Salehi (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 distortions and the TFPs separately. Intuitively, the endogenous input expenditure and consumption shares are affected by the distortions and TFPs differently, and we can use these different effects to separately identify distortions 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, the ratio of the net (of distortion) prices needs to be observed

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[1]Jones (2011, 2013) identify distortions as Hsieh and Klenow (2009) by relating to the undistorted country, the United States. This, as he acknowledges, assumes that the U.S. same input-output structure applies to other countries. Tombe and Zhu (2015) identify and evaluate importance of both internal and external distortions in a model without the input-output structure. Bigio and La'O (2016) study labor and efficiency wedges in an input-output framework and exploit the constancy of the technological parameters over the business cycle to identify distortions.

to separate the sectoral TFPs and the distortions. The consumption side under the CES gives the ratio of the prices in terms of the consumption shares and hence allows us to identify the distortions and TFPs separately even if net prices are not observable. 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 distortions.[2]

Our second theoretical result is to analytically derive the elasticity of the changes in the input-output shares to the changes in the distortions 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 distortions or TFPs in another country-sector pair (say, the distortions 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 distortions. Importantly, we have that the elasticity of input-output shares are non-zero and non-constant, 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 distortions on expenditure shares, and the indirect effects from changes in the prices of intermediate goods.

We now turn to the empirical results of the paper. We derive all the data needed to measure distortions and TFPs 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 distortions over this period, and about 2 million elasticities of input-output shares and world's GDP to changes in distortions.

In our model, changes in distortions 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. We first study how changes in the internal distortions affect the endogenous structure of the economy of individual countries. For the U.S. and China's input-output tables we compute how their own input-output structure change with respect to changes in their own internal distortions. These two countries are chosen as important illustrative examples with different input-output structure 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 distortions of, for example, manufacturing

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[2]We also discuss that our methodology applies more broadly if one is interested in identifying the changes in the distortions and TFPs – the model then can have a number of additional dimensions of heterogeneity.

industries. The share of manufacturing inputs by all sectors increases because of the direct effects of the lower distortion, the indirect effects on the price of manufacturing, and the substitution effect of other sectors becoming more expensive. We then compute the effects on the U.S. input-output structure from changes in internal distortions in China – the cross-elasticity of the U.S. economy structure to Chinese distortions.

Our second exercise is to compute the global elasticity of expenditure shares and elasticity of world's real GDP to changes in internal distortions. Specifically, we compute the change in expenditure shares in all countries and sectors in the world from a 10 percent reduction in internal distortions all over the world. The main conclusion is that changing all internal distortions 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 the internal distortions can by seen by ranking the top 60 elasticities of the world's GDP to the distortions of a sector in a given country. The largest such internal elasticity - that of China's construction sector has the same size as the elasticity of the world's GDP to *all* of the external distortions in the United States.

We then compute the elasticity of world's GDP with respect to external distortions. The principal result here is that the elasticity of internal distortions is an order of magnitude larger than the elasticity of external distortions. 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. The closest in terms of the result on the internal versus external distortions is the work by Tombe and Zhu (2015). They show that for China, the internal distortions play a much larger role for aggregate productivity and output.

Next, we compute the distortions 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 distortions and their distribution across countries. Therefore, aggregate measures of relative distortions across countries can give only a partial view of the degree of distortions across countries, since the country level distortions mask the high heterogeneity at the more disaggregate level.

We conclude with the computation of the change in global input-output shares and world's real GDP to the actual changes in domestic distortions over the period 1995-2011. In other words, we show how the world's input-output structure in 2011 would have changed if internal distortions 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 distortions. We observe significant changes in the domestic input-output relationships, that is, those would have been more important today if distortions would have stayed at the level of 1995. We also

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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.[3] Consistent with the heterogeneity in the growth rate of internal distortions, we find a differential impact on world's GDP to the actual change in local distortions across sectors and countries.

We now briefly discuss the connection to the literature. The closest in spirit to our paper is the macroeconomic literature that emphasizes domestic distortions (misallocation) across sectors and firms (e.g. Jones 2010, 2011)[4], Restuccia and Rogerson (2008, 2013), Hsieh and Klenow (2009). Our paper also relates to recent studies that show how local productivity shocks or distortions spread within a country (see e.g. Caliendo, Parro, and Rossi-Hansberg 2014, Fajgelbaum, Morales, Serrato, and Zidar 2015) and to the literature on aggregate consequences of idiosyncratic shocks that emphasizes the departure from the Cobb-Douglas assumptions (Atalay 2017, Baqaee and Farhi 2017, and Carvalho, Nirei, Saito, and Tahbaz-Salehi 2017).

The paper is organized as follows. In Section 2 we present our model of the input-output structure of the world economy. In Section 3 we derive our main theoretical results; the sufficient statistics to identify distortions and TFPs, and the sufficient statistic for the changes in the input-output structure to changes in the internal distortions. Section 4 describes the data and calibration strategy, and Section 5 presents the input-output share elasticities, and world's GDP elasticities to changes in distortions, as well as the computed actual changes in distortions and their impact on the world's input-output structure. Finally, Section 6 concludes.

2 Model

The world economy consists of N countries (indexed by i, n). Each country has J sectors (indexed by j, k). Each country is endowed with one unit of equipped labor and the unit mass of agents.[5]

The production function for intermediate good Q_{ij} in the country i and sector j is

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[3]Adamopoulos, Brandt, Leight, and Restuccia (2017) and Brandt, Kambourov, and Storesletten (2016) are the recent analyses of the evolution of distortions in China at the firm and sectoral level.

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

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

Cobb-Douglas:

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

where A_{ij} is the TFP, L_{ij} is amount of labor allocated to sector j, M_{ij} is the amount of materials used by the sector j, and $\beta \in [0,1]$.[6]

The production function for the final goods (materials) M_{ij} in the country i and sector j is CES:

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

where $n = 1,..,N$; $k = 1,...,J$, and the sector i in the country j sources Q_{ijnk} of final goods from the sector k in the country n. The input weight ι_{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. There is perfect competition in both the final goods sectors and the materials sectors.[7]

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

$$\sum_{j=1,...,J} L_{ij} = 1, \ \forall i \in \{1,...,N\}.$$

We denote by w_i the wage in the country i.

The unit price of the final good Q_{ij} is given by:

$$c_{ij} = \frac{1}{A_{ij}} w_i^{\beta} P_{ij}^{(1-\beta)},$$

where P_{ij} denotes the price of the good Q_{ij}.

An agent in country i maximizes the CES utility:

$$U(C_i) = \left(\sum_{j=1,...,J} \chi_{ij} C_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}},$$

where C_i is the composite consumption good, C_{ij} are the consumption goods from sector j

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[6]To simplify the notation, we suppress the sector and country indexes for the share of value added in gross output β. However, this simplification does not affect our theoretical results, and in the empirical part, we account for the heterogeneity in the value added shares across sectors and countries observed in the data.

[7]This assumption is also not essential as, for example, heterogenous markups represent themselves as the sector level distortions.

in country i, and χ_{ij} are demand shifters applied to goods j in country i.

Sourcing a good from country n, sector k to country i, sector j entails a cost $\tau_{ijnk}c_{nk}$. We call τ_{ijnk} the distortion or the wedge. Note that we do not impose symmetry: $\tau_{ijnk} \neq \tau_{nkij}$. We also assume that there is no distortion when a sector sources materials from itself, $\tau_{ijij} = 1$.

We call the distortions that affect sectors within a country, τ_{ijik}, *internal distortions*. Examples of such distortions are sector-specific taxes, regulations or policies that favor sourcing from one sector over another, or markups. We call the distortions that affect sectors across countries, τ_{ijnk} $(i \neq n)$, *external distortions*. Examples of such distortions are trade costs, implicit subsidies or tariffs for imports or exports, or differences in contract enforcement.

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

$$\gamma_{ijnk} \equiv \frac{X_{ijnk}}{\sum_{m=1}^{N} \sum_{h=1}^{J} X_{ijmh}},$$

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

Denote the share of consumption of the consumption good from sector j in the aggregate consumption of country i by α_{ij}. Formally,

$$\alpha_{ij} \equiv \frac{P_{ij}C_{ij}}{\sum_{k=1}^{J} P_{ik}C_{ik}}.$$

Similar to the intermediate expenditure shares γ_{ijnk}, the final expenditure shares α_{ij} are directly observable in any world input-output matrix that contain data on final expenditure in a given country sourced from different sectors and countries.

3 Theoretical Results

3.1 Sufficient Statistics for Identification of Distortions and TFPs

In this section we propose a method to separately decompose the TFPs and the distortions in the input-output economy – this is the first main theoretical result of the paper. The key

to the results is threefold. First, the CES structure of production of both the intermediate goods and consumption yields the expenditure shares γ and consumption shares α varying with TFP and distortions. Second, TFP and distortions 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, and hence is applicable when the prices are not observable.

First, consider the internal distortions and the sectoral TFP for country i. We start with the production side of the economy. The share of the input of the sector k in the sector j is:

$$\gamma_{ijik} = \frac{(\tau_{ijik}c_{ik})^{-\theta}\iota_{ik}^{1+\theta}}{\sum_{m=1}^{N}\sum_{h=1}^{J}(\tau_{ijmh}c_{mh})^{-\theta}\iota_{mh}^{1+\theta}} = \frac{A_{ik}^{\theta}\tau_{ijik}^{-\theta}w_i^{-\theta\beta}P_{ik}^{-\theta(1-\beta)}\iota_{ik}^{1+\theta}}{\sum_{m=1}^{N}\sum_{h=1}^{J}A_{mh}^{\theta}\tau_{ijmh}^{-\theta}w_m^{-\theta\beta}P_{mh}^{-\theta(1-\beta)}\iota_{mh}^{1+\theta}},$$

which in turn can be written as:

$$\gamma_{ijik} = \frac{A_{ik}^{\theta}\tau_{ijik}^{-\theta}P_{ik}^{-\theta(1-\beta)}\iota_{ik}^{1+\theta}}{\left(P_{ij}/w_i^{\beta}\right)^{-\theta}}, \tag{1}$$

where the sectoral price index is given by

$$P_{ij} = \left(\sum_{m=1}^{N}\sum_{h=1}^{J}A_{mh}^{\theta}\tau_{ijmh}^{-\theta}w_m^{-\theta\beta}P_{mh}^{-\theta(1-\beta)}\iota_{mh}^{1+\theta}\right)^{-1/\theta}.$$

Dividing the input shares, γ_{ikik} and γ_{ijik}, to cancel the sector k TFP, A_{ik}, and the wage, w_i, and using that $\tau_{ikik} = 1$, we get the expression for the distortion as a function of the sectoral prices:

$$\tau_{ijik} = \left(\frac{P_{ij}}{P_{ik}}\right)\left(\frac{\gamma_{ikik}}{\gamma_{ijik}}\right)^{\frac{1}{\theta}}. \tag{2}$$

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

$$\tilde{\tau}_{ijik} \equiv \tau_{ijik}\left(\frac{A_{ij}}{A_{ik}}\right)^{\frac{1}{\beta}}\left(\frac{\iota_{ij}}{\iota_{ik}}\right)^{\frac{1+\theta}{\beta}} = \left(\frac{\gamma_{ijij}}{\gamma_{ikik}}\right)^{\frac{1}{\theta\beta}}\left(\frac{\gamma_{ikik}}{\gamma_{ijik}}\right)^{\frac{1}{\theta}};$$

therefore, $\tilde{\tau}_{ijik}$ can be identified but not the TFPs and distortions separately. In order to separate distortions from TFPs, we now turn to the consumption side of the economy.

The consumer's problem yields the following consumption share in country i, sector j:

$$\alpha_{ij} = \frac{P_{ij}C_{ij}}{\sum_{k=1}^{J} P_{ik}C_{ik}} = \chi_{ij} \left(\frac{P_{ij}}{P_i}\right)^{1-\sigma}, \tag{3}$$

where

$$P_i = \left[\sum_{j=1,\dots,J} \chi_{ij} (P_{ij})^{1-\sigma}\right]^{1/(1-\sigma)} \tag{4}$$

is the ideal price index.

Dividing the shares of consumptions for sector j and k gives the ratio of sectoral prices:

$$\frac{P_{ij}}{P_{ik}} = \left(\frac{\alpha_{ij}/\chi_{ij}}{\alpha_{ik}/\chi_{ik}}\right)^{\frac{1}{1-\sigma}},$$

and after substitution the expression for the distortion:

$$\tau_{ijik} = \left(\frac{\gamma_{ikik}}{\gamma_{ijik}}\right)^{\frac{1}{\theta}} \left(\frac{\alpha_{ij}/\chi_{ij}}{\alpha_{ik}/\chi_{ik}}\right)^{\frac{1}{1-\sigma}}.$$

Another way to gain intuition is to rewrite

$$\tau_{ijik} \left(\frac{\alpha_{ik}/\chi_{ik}}{\alpha_{ij}/\chi_{ij}}\right)^{\frac{1}{1-\sigma}} = \left(\frac{\gamma_{ikik}}{\gamma_{ijik}}\right)^{\frac{1}{\theta}}.$$

Hence, the distortion is the wedge in the first order condition whereas the undistorted economy equates the relative consumption shares to the input shares. The analysis of the external distortions is identical with the exception that the final expression would also include the ratio of ideal prices in countries i and n. Now, under the assumption that demand shifters are time invariant and orthogonal to distortions we can identify the changes in distortions over time using only intermediate and consumption shares. Namely, we can identify $\hat{\tau}$ where $\hat{\tau} \equiv \tau_{t+1}/\tau_t$, and more generally any variable with "hats" means changes over time.

We summarize the results in the first main proposition of the paper:

Proposition 1. *In a world with N countries (indexed by i, n) and J sectors (indexed by j, k) the change in internal distortions are given by:*

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

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The change external distortions are given by:

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

The change in TFPs are given by:

$$\frac{\hat{A}_{ij}}{\hat{A}_{ik}} = \left(\frac{\hat{\gamma}_{ijij}}{\hat{\gamma}_{ikik}} \right)^{\frac{1}{\theta}} \left(\frac{\hat{\alpha}_{ij}}{\hat{\alpha}_{ik}} \right)^{-\frac{\beta}{1-\sigma}}.$$

The proposition above gives a very simple closed-form expression for the sufficient statistics formula to identify the change in external and internal distortions separately from the TFPs. All of the formulas are expressed in terms of the small set of directly observable empirical counterparts from the world input-output table. Note that the TFPs are calculated up to one reference sector for a country.

We now discuss the generality and the limitations of the proposition. The key to the analysis is that we use both the consumption and the production shares to separately identify distortions and the TFPs. The generality of the result can be summarized as follows: we can identify as many elements of the model (i.e., distortions and TFPs) as there are CES shares of consumption and production. Otherwise, only the composite distortion $\tilde{\tau}$ can be identified.

One generalization of Propositon 1 is for the case in which input weights are origin and destination specific, ι_{ijnk}. At the same time, assuming that the preference parameters χ_{ij} and production parameters ι_{ijnk} are not changing over time, they would immediately drop out if we consider the change of the distortion across time. The same principle applies to other modifications of the model such as, for example, adding consumption distortions. If these additional elements do not change over time, one can still identify the changes in the distortions. However, if we impose further restrictions over the demand shifters we can also identify the level of distortions. This result is summarized in the following Corollary.

Corollary 1. *Under uniform demand shifters, in a world with N countries (indexed by i, n) and J sectors (indexed by j, k) the level of internal distortions are given by:*

$$\tau_{ijik} = \frac{(\gamma_{ikik}/\gamma_{ijik})^{\frac{1}{\theta}}}{(\alpha_{ik}/\alpha_{ij})^{\frac{1}{1-\sigma}}}.$$

The level of external distortions are given by:

$$\tau_{ijnk} = \frac{(\gamma_{nknk}/\gamma_{ijnk})^{\frac{1}{\theta}}}{(\alpha_{nk}/\alpha_{ij})^{\frac{1}{1-\sigma}}} \left(\frac{P_i}{P_n} \right).$$

Note that the result in Corollary 1 shows how to measure the level of distortions. even under the presence of weights in the production function of intermediates. The result does rely on the assumption of uniform demand shifters. Consequently, in the quantitative analysis in Section 5 we compute growth rates in distortions and TFPs, and the elasticities of input-output shares and world's GDP to changes in distortions; and therefore, these extensions to our model do not affect our quantitative results.

We comment on the two key difference with the results of the macroeconomic literature that focuses on misallocations and distortions – the use of the CES production function, and the use of the CES consumption to derive the ratio of the prices. In Hsieh and Klenow (2009), the production function is Cobb-Douglas. They identify the distortions by making reference to the undistorted country. This amounts in our context to assuming that either the net (of distortion) as well as gross (with distortion) 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 distortions. Besides, Cobb-Douglas assumption implies that the expenditure and the consumption shares are exogenous and do not change with distortions and TFPs.[8]

Notice that to compute internal distortions, external distortions, or TFPs, we do not need to solve for the general equilibrium of the model, as they can be directly computed using data on intermediate and final expenditure shares, conditional on values for the elasticities σ and θ. As discussed above, we do not need to use price data or impose symmetry in distortions either, different from common approaches followed in the trade literature to compute external distortions.[9] It is also immediately clear how to extend the analysis to

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[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.

[9] Note that if sectoral prices were observable equation (2) could be used to identify the distortions. In practice, sectoral prices across countries can be found in some existing databases such as the International Comparison Program (ICP), or can be inferred using sectoral deflators from other databases such as EU-KLEM or the GGDC 10-Sector Database. However, there are two major issues with this approach. First, using price data from these or other sources is always going to constraint the computation of internal distortions due to the lack of consistent time series data or the lack of price data for non-tradable industries, the reduced number of countries in the database, the reduced number of sectors, or due to inconsistencies between the definition of prices in the price databases (for instance, deflators or PPI indexes), and their

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 (1), 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.

3.2 Sufficient Statistics for the Changes in the Input-Output Structure

The second set of the theoretical results that we derive is how changes in sectoral TFPs or distortions affect the input-output structure of the economy. The main feature of our model is that the input-output matrix is endogenous. That is, following the change in sectoral TFPs or distortions, the expenditure shares (or input-output shares) change as well. In this section, we analytically derive the elasticities of the input-output shares with respect to changes in the sectoral TFPs or internal distortions.

We first derive an intermediate result that expresses the changes in the expenditure shares in terms of the higher-level "policy elasticities". That is, the policy elasticities are derived in terms of the endogenous prices rather than in terms of the primitives. If the prices are observable, these elasticities are easily estimated. This proposition allows us to clearly identify the major forces affecting the endogenous change in the input-output structure of the economy to the change in the distortions.

Proposition 2. *The elasticity of input-output share* γ_{ijnk} *with respect to changes in all distortions* τ *in the world is given by*

$$\frac{dlog\gamma_{ijnk}}{dlog\tau} = -\theta + \theta\frac{dlogP_{ij}}{dlog\tau} - \theta(1-\beta)\frac{dlogP_{nk}}{dlog\tau} - \theta\beta\frac{dlogw_n}{dlog\tau}.$$

According this proposition, the elasticity of the expenditure share γ_{ijnk} to changes in distortions depends on four forces. First, there is a direct effect of a reduction in τ_{ijnk} on γ_{ijnk}, with an elasticity of $-\theta$. Specifically, a reduction in τ_{ijnk} makes inputs purchased by the country-sector pair ij from the country-sector pair nk cheaper, thus the expenditure share spent on goods from nk increases. Second, a reduction in distortions in sector j, either from buying from nk or any other origin sector-country, will reduce the price index in the country-sector pair ij. Thus the share spent on goods from sector j increases and the share

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counterpart in the model or in the input-output data. Second, and perhaps more importantly, the measured prices do not take into account implicit price distortions such as differences in contract enforcement or implicit subsidies.

spent on goods from sector k (or any other sector-country) decreases. This second effect depends on θ, and on the elasticity of the price index in the country-sector ij with respect to changes in distortions. The third effect captures the impact on the price index in the destination country-sector P_{nk}. A reduction in distortions of selling goods from country n sector k to the country-sector ij (or to any other country-sector) reduces the price index in the country-sector nk, which increases the expenditure share on those goods. This third effect depends on θ, the share of materials in gross output $(1 - \beta)$, and on the elasticity of the price index in the country-sector ij with respect to changes in distortions. The fourth effect, the change in wages, depends on θ, the share of value added in gross output β, and the wage elasticity to changes in distortions.

We now turn to derive a closed-form expression for the input-output share elasticity $dlog\gamma_{ijnk}$ with respect to distortions or TFPs. In Appendix 1, we derive the elasticity of the whole world's input-output structure with respect to changes in distortions 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 distortions and productivities is given by the following equation:

$$\Gamma = \mathcal{F}(\theta, \beta, \gamma_{lsmh})A + \mathcal{H}(\theta, \beta, \gamma_{lsmh})\tau + \mathcal{O}(\theta, \beta, \gamma_{lsmh})\omega,$$

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

To reduce the notational burden, 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 γ_{ijik} to a change in the distortion τ_{ijik}. Totally differentiating the expression for the prices and for the input-output shares, we obtain the following proposition.

Proposition 3. *Consider sectors j and k of a country i. Let*

$$\tilde{\gamma}_{isip} \equiv \frac{\gamma_{isip}}{1 - \gamma_{isip}(1 - \beta)},$$

for $s, p \in \{j, k\}$.

The elasticities of the input-output shares with respect to distortions are given by:

$$\frac{d \log \gamma_{ijik}}{d \log \tau_{ijik}} = -\theta \frac{1 - \tilde{\gamma}_{ijik}}{1 - \tilde{\gamma}_{ikij} (1 - \beta) \tilde{\gamma}_{ijik} (1 - \beta)},$$

$$\frac{d \log \gamma_{ikij}}{d \log \tau_{ijik}} = -\theta \frac{\tilde{\gamma}_{ijik} (1 - \beta) (1 - \tilde{\gamma}_{ikij})}{1 - \tilde{\gamma}_{ikij} (1 - \beta) \tilde{\gamma}_{ijik} (1 - \beta)}.$$

The elasticities of the input-output shares with respect to sectoral TFPs are given by:

$$\frac{d \log \gamma_{ijik}}{dA_{ij}} = \theta \frac{1}{1 - \tilde{\gamma}_{ikij} (1 - \beta) \tilde{\gamma}_{ijik} (1 - \beta)} \left[\tilde{\gamma}_{ikij} \tilde{\gamma}_{ikik} (1 - \beta) - \tilde{\gamma}_{ijij} \right],$$

$$\frac{d \log \gamma_{ikij}}{d \log A_{ij}} = \theta \left[1 - \frac{1}{1 - \tilde{\gamma}_{ikij} (1 - \beta) \tilde{\gamma}_{ijik} (1 - \beta)} \left(- (1 - \beta) \tilde{\gamma}_{ijij} + \tilde{\gamma}_{ikij} \tilde{\gamma}_{ikik} (1 - \beta) \right) \right].$$

This proposition provides the closed-form solution for elasticities in terms of easily observable empirical variables. We now briefly illustrate the intuition for this result on an even simpler case. Suppose that $\gamma_{ikij} = 0$, that is, sector k does not purchase any inputs from sector j. It is easy to show that either in the case of changing τ_{ijik} or A_{ij}, the effect on the price of sector k is zero, $d \log P_{ik} = 0$. The elasticity of the price in sector j also takes a very simple form, depending only on the relevant sector's share:

$$\frac{d \log P_{ij}}{d \log \tau_{ijik}} = \tilde{\gamma}_{ijik}; \quad \frac{d \log P_{ij}}{d \log A_{ij}} = -\tilde{\gamma}_{ijij}.,$$

This further leads to very simple expressions for the elasticities of the shares:

$$\frac{d \log \gamma_{ijik}}{d \log \tau_{ijik}} = -\theta (1 - \tilde{\gamma}_{ijik}); \quad \frac{d \log \gamma_{ikij}}{d \log \tau_{ijik}} = -\theta (1 - \beta) \tilde{\gamma}_{ijik},$$

and

$$\frac{d \log \gamma_{ijik}}{d \log A_{ij}} = -\theta \tilde{\gamma}_{ijij}; \quad \frac{d \log \gamma_{ikij}}{d \log A_{ij}} = \theta \left[1 + (1 - \beta) \tilde{\gamma}_{ijij} \right].$$

This implies that $\frac{d \log \gamma_{ijik}}{d \log \tau_{ijik}}$ is increasing in γ_{ijik} and $\frac{d \log \gamma_{ikij}}{d \log \tau_{ijik}}$ is decreasing in γ_{ijik}; and that $\frac{d \log \gamma_{ijik}}{d \log A_{ij}}$ is increasing in γ_{ijij} and $\frac{d \log \gamma_{ikij}}{d \log A_{ij}}$ is decreasing in γ_{ikik}.

With this set of theoretical results, we proceed in the next section to compute the world's input-output elasticities to changes in distortions, to identify the actual growth rate in distortions over time, and to study the impact of these actual changes in distortions on the world's input-output structure. We start next section by describing the data needed for our quantitative exercises.

4 Data and Calibration

All the data needed to measure distortions and TFPs, and to compute the empirical exercises in the next section come from the World Input-Output Database (WIOD). 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. This data is integrated into a world input-output table, which also provides gross output and value added for each sector and country. In Appendix 2 we provide the exact 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 γ_{ijnk} 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, we use the standard values of the elasticities in the literature $\theta = \sigma = 4$.

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 an 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 represents 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 80th 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.

Figure 1: Global expenditure shares across sectors and countries in 2011
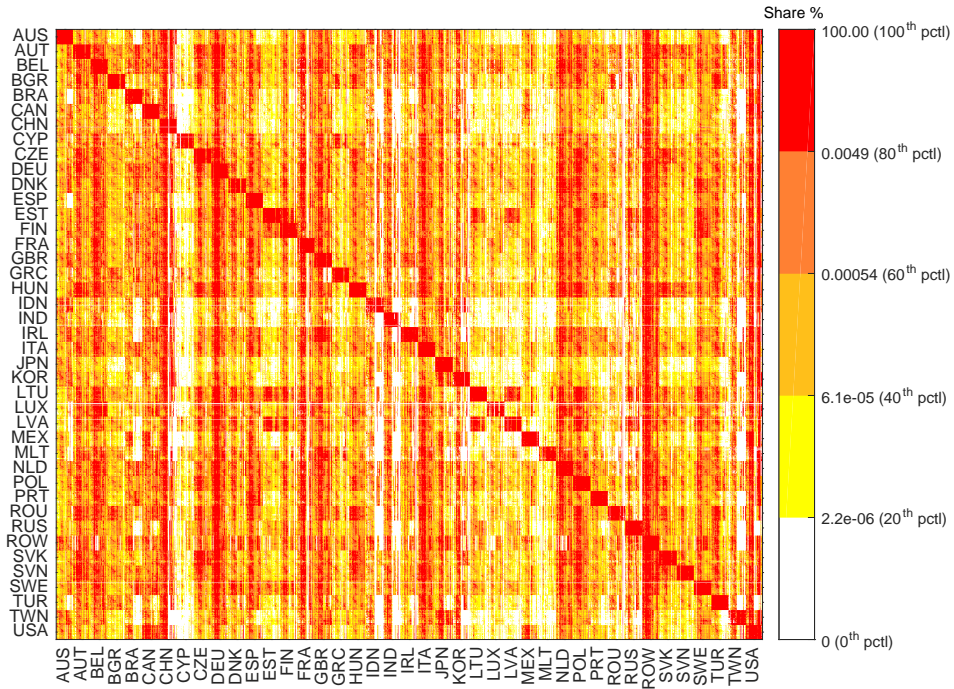
We want to highlight two relevant features from the world input-output table. First, the diagonal is strong, that is, the red squares along the diagonal of the figures mean that the domestic input-output transactions tend to be stronger than the cross-country transactions. However, the importance of 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 domestic input-output shares fall below the 80th 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 world. Later, we discuss further how these features shape the elasticities of GDP and expenditure shares with respect to changes in distortions.

Figure 2: U.S. expenditure shares across sectors and countries in 2011
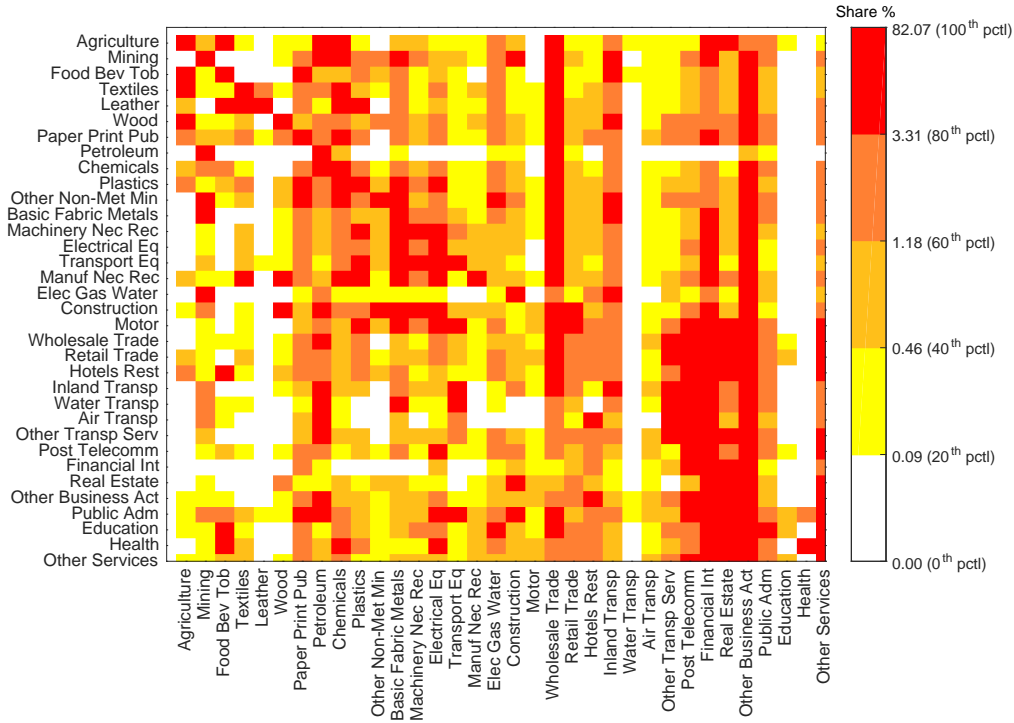
In Figure 2, we reproduce the input-output for the U.S. economy presented as a heatmap. The y-axis (rows) shows the buyer sectors from each seller sector in the x-axis (columns).In the figure, for a given seller industry, we aggregated U.S. purchases from all countries in the world in that industry. Similar to the previous figure, the colors represents different percentiles that are labeled on the right hand side of the figure. For instance, the 80th percentile in the figure corresponds to a U.S. 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.

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Figure 3: China's expenditure shares across sectors and countries in 2011
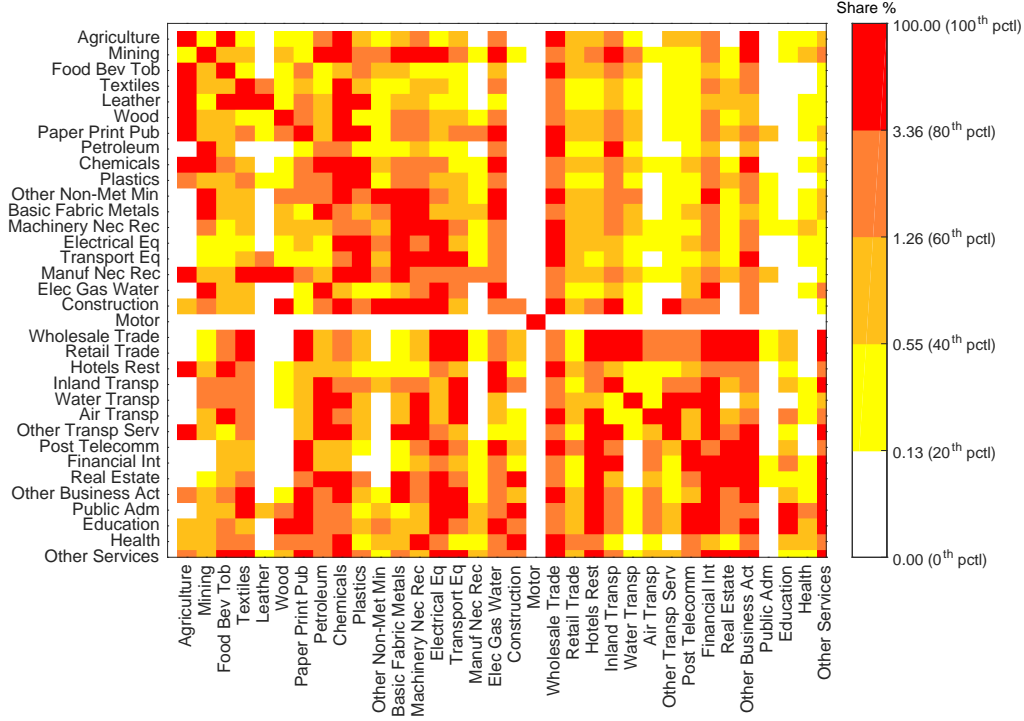
In the next section, we show the elasticities of these input-output tables in these countries to changes in internal distortions, as well as the cross-country elasticities where distortions in other countries change.

5 Quantitative Analysis

In this section, we discuss the empirical results of the paper.

Before turning to the results, we show how to close the model developed in Section 2, and describe the equilibrium conditions needed to compute the general equilibrium effects in the model. Specifically, we impose the market clearing condition given by:

$$w_i L_i = \sum_{k=1}^{J} \sum_{n=1}^{N} \frac{1 - \beta_{nk}}{\beta_{nk}} \gamma_{nkij} X_{nk}. \tag{5}$$

The equilibrium of this economy is therefore defined by equations (1), (3), (4), and (5).

5.1 Elasticities and Endogenous IO

In our model, changes in distortions 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 distortions. In this section, we emphasize this point by computing the elasticity of the input-output shares to changes in internal distortions. We first focus on the U.S. and China input-output structure, and compute how their input-output structure change with respect to changes in their own internal distortions. We then compute the effects on the U.S. input-output structure from changes in internal distortions in China – the cross-elasticity of China's internal distortions on the United States. In the next section we take a global view on the impact of internal distortions on the world's input-output structure.

We start by computing how the U.S. input-output structure would change with respect to a 10 percent decline in internal (within the United States) distortions in the manufacturing industries. The results are displayed in Figure 4.

The upper two panels show the effects of the decline in the distortions of selling goods to manufacturing industries from any industry. The lower two panels show the effects of the decline in distortions of buying goods from the manufacturing industries by any industry. We show the change in expenditure shares to changes in internal distortions in absolute terms on the left panels, and in percent changes on the right panels. We can see from the figure how the U.S. input-output table is impacted by changes in distortions in the manufacturing industries. In particular, we observe that manufacturing sectors buy more from other manufacturing sectors. Since it is cheap for manufacturing industries to buy intermediate inputs from everywhere, they will buy proportionally more from the manufacturing industries because those industries experience a larger decline in the price index. In the lower panels, we observe that all sectors, and especially non-manufacturing industries, substitute inputs from non-manufacturing industries for manufacturing inputs, as the latter are now a cheaper source of inputs after the decline in distortions. These two findings are in line with the effects from the closed-form elasticities in Proposition 2 discussed in the previous section.
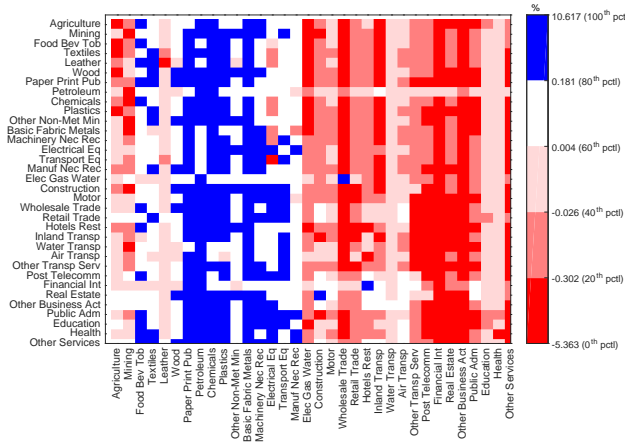
Figure 4: Change in U.S expenditure shares to U.S. internal distortions in manufacturing
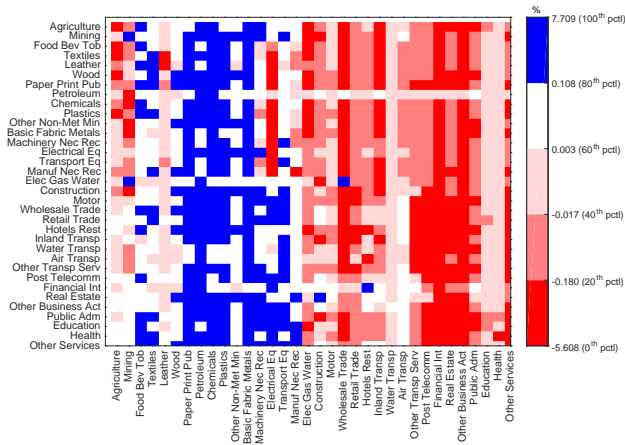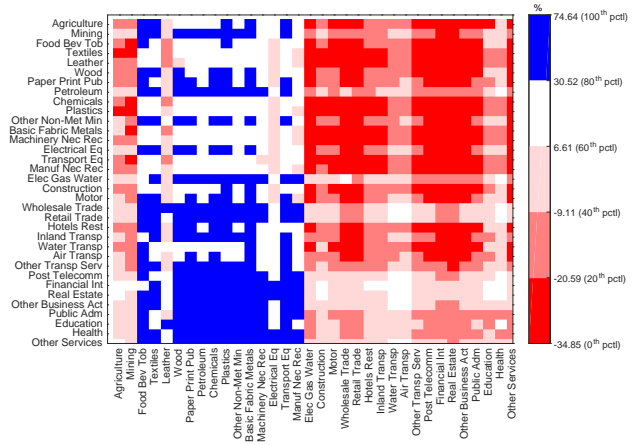

(a) U.S. manufacturing industries as buyers
(absolute changes)
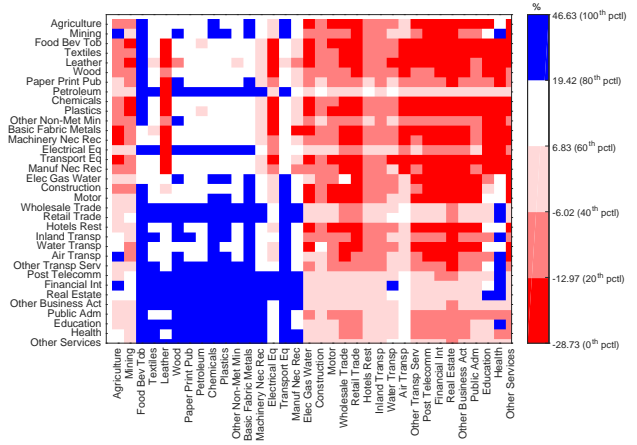
(b) U.S. manufacturing industries as buyers
(percentage changes)

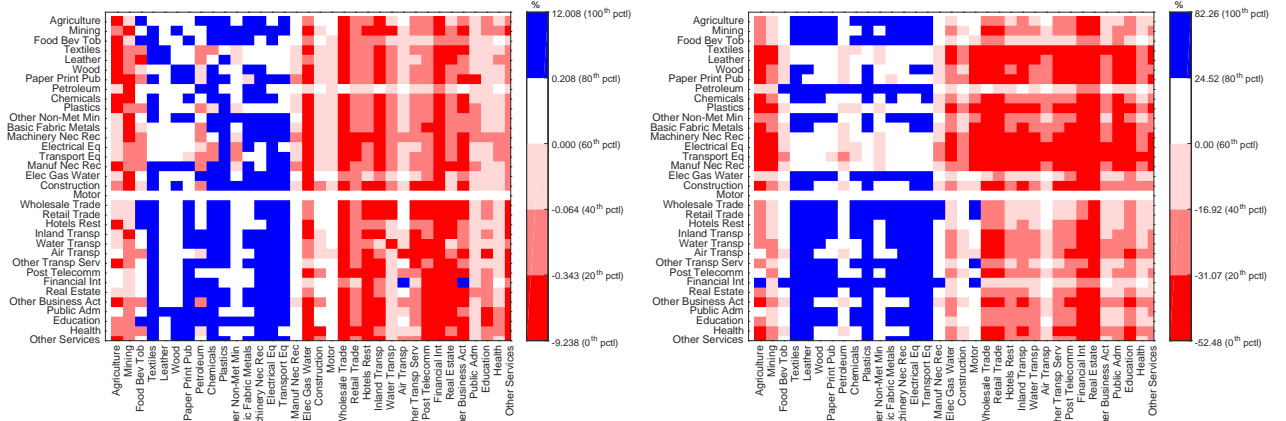(c) U.S. manufacturing industries as sellers
(absolute changes)

(d) U.S. manufacturing industries as sellers
(percentage changes)

In Figure 5, we perform the same exercise but for a different economy, China, as a way
of confirming whether the findings for the U.S. 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 distortions 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
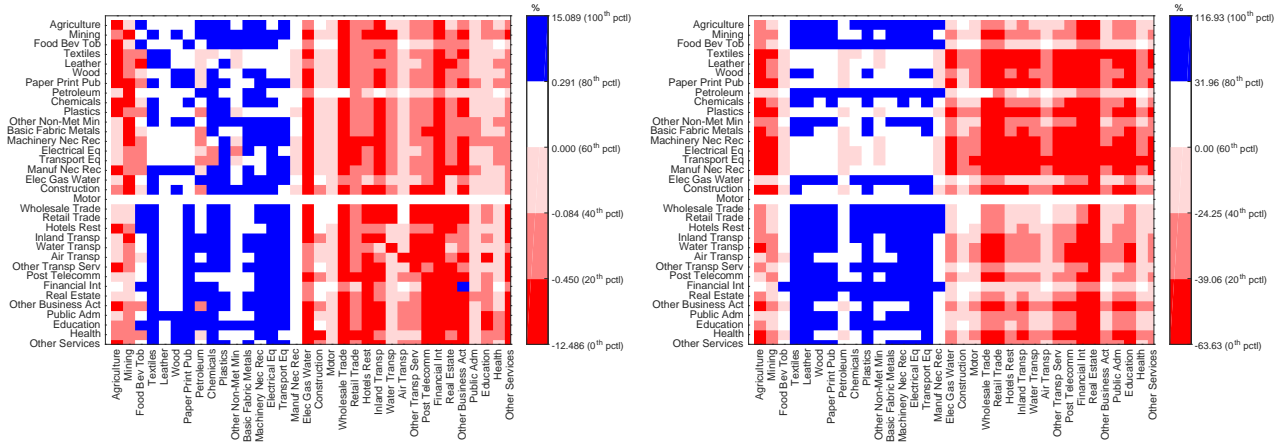
manufacturing industries increase their importance as suppliers for the rest of the economy.

Figure 5: Change in China's expenditure shares to China's internal distortions in manufacturing

(a) China's manufacturing industries as buyers (absolute changes)

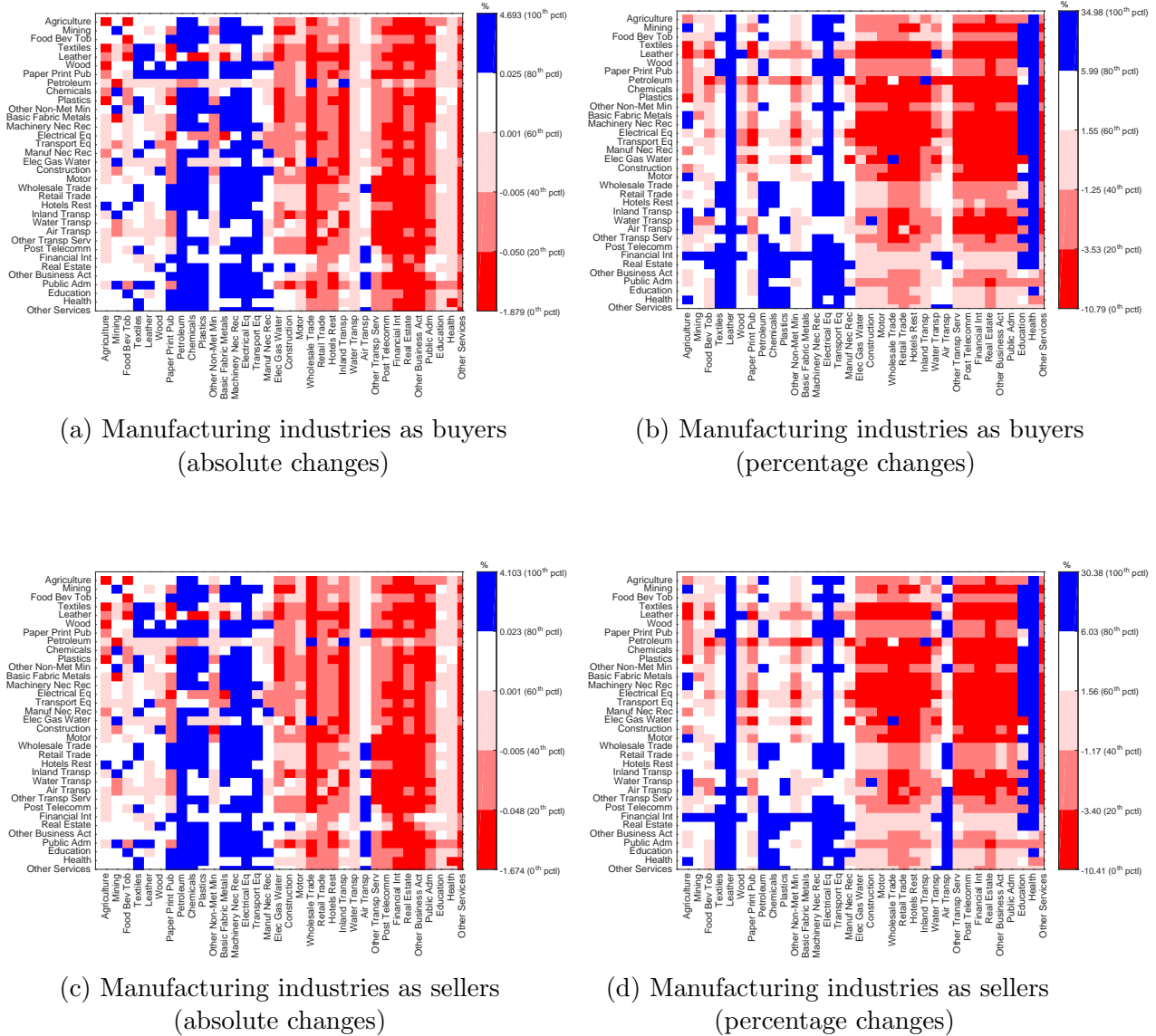(b) China's manufacturing industries as buyers (percentage changes)

(c) China's manufacturing industries as sellers (absolute changes)

(d) China's manufacturing industries as sellers (percentage changes)

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 U.S. economy is different from the Chinese one, and therefore the effects of the changes in distortions at the more disaggregate level are different in these two economies.

For instance, the share of manufacturing purchases in total expenditure increases by 9.3 percent in absolute terms in the United States, and 12.3 percent in China. 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 heterogenous input-output effects from changes in distortions across countries.

Figure 6: Change in U.S. expenditure shares to China's internal distortions in manufact.

(a) Manufacturing industries as buyers
(absolute changes)

(b) Manufacturing industries as buyers
(percentage changes)

(c) Manufacturing industries as sellers
(absolute changes)

(d) Manufacturing industries as sellers
(percentage changes)

The final exercise we perform in this section aims at computing the cross-country effects of changes in internal distortions in the manufacturing sectors. Specifically, we compute the change in the U.S. input-output shares from a 10 percent reduction in the internal distortions 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 distortions as buyers of goods from any industries, and the lower panels show the change in internal distortions from selling to 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 U.S. economy purchases proportionally more inputs from the manufacturing industries, and also manufacturing industries increase their importance as suppliers for the rest of the U.S. economy. This highlight the fact that the Chinese manufacturing is more connected to the U.S. manufacturing sectors than to other industries. Second, there are also some relevant effects in U.S. non manufacturing industries such as transport services, health, and education, which increase their importance as suppliers.

These two results in addition to the previous ones highlight how complex the input-output relationships within countries and across countries are, and given this, how important is to keep track of the endogenous changes in them as a results of changes in distortions anywhere in the world.

5.2 World Elasticities

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

In Figure 7, we start with a similar computation to the one performed in the previous section, 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 distortions all over the world. The main conclusion we get from the figure is that changing internal distortions at the same time has dramatic change in the world's input-output structure, which reinforces our findings in the previous section. 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.

Figure 7: Change in global expenditure shares to internal distortions in manufacturing

(a) Global expenditure shares
(absolute changes)

(b) Global expenditure shares
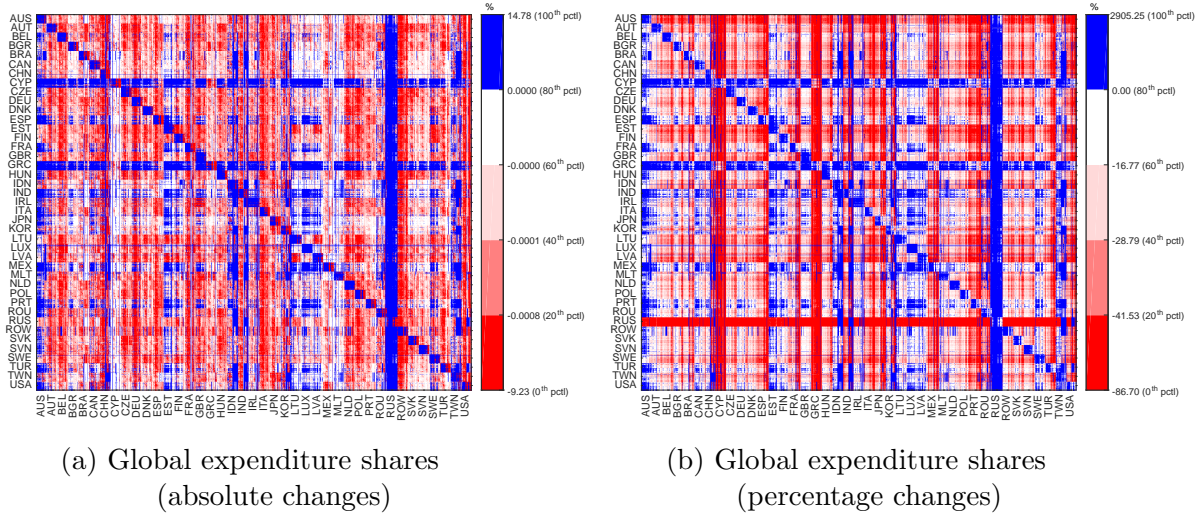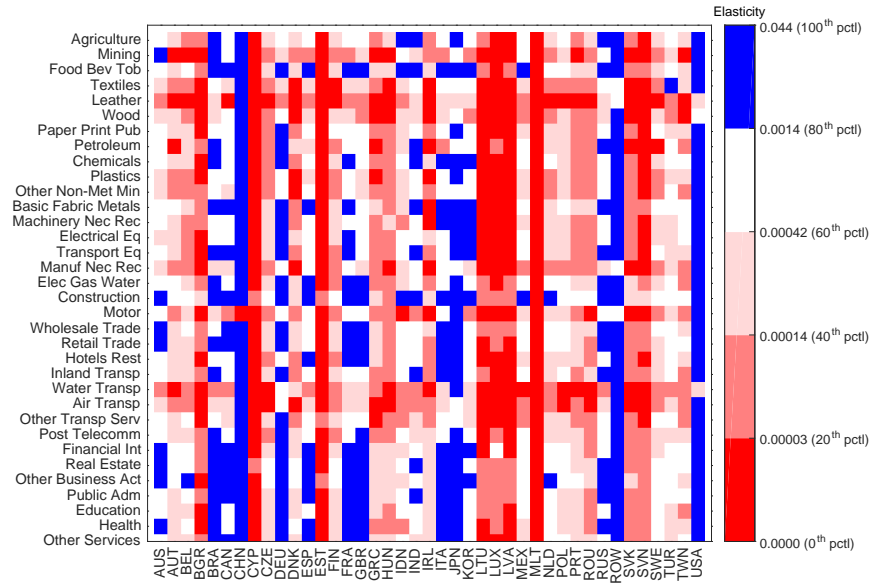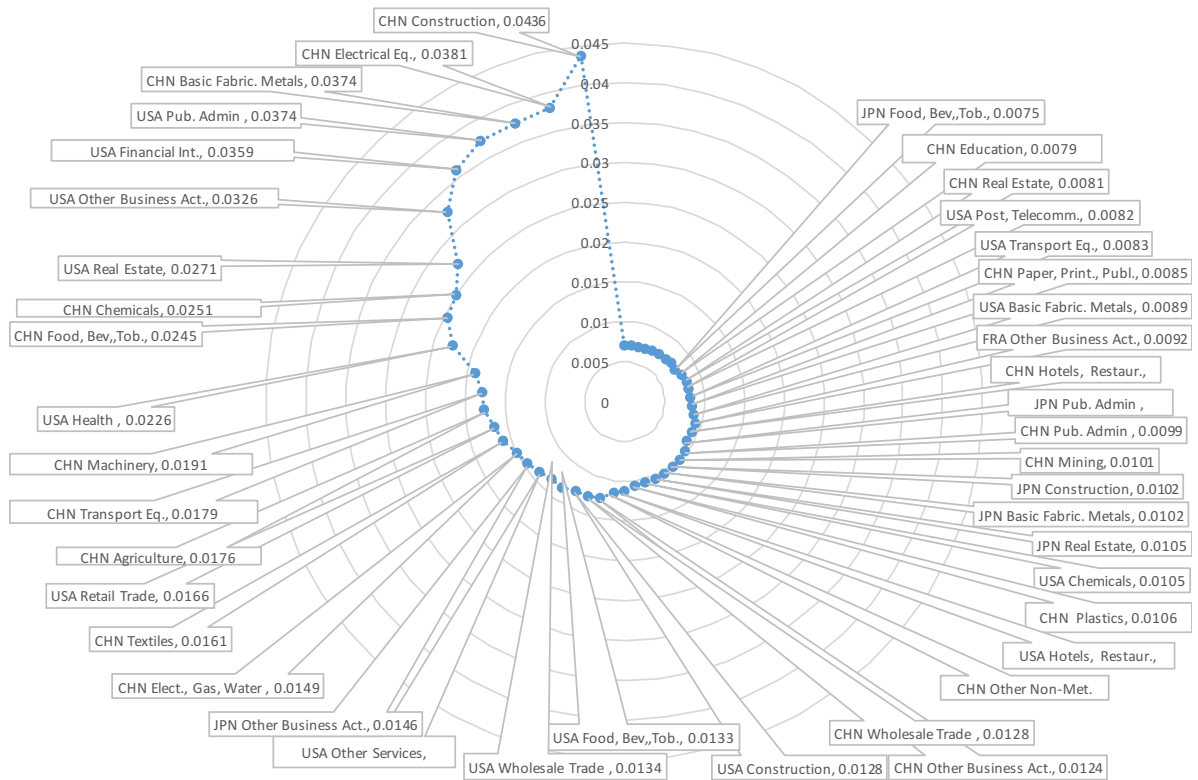(percentage changes)

Figure 8: World's real GDP elasticity to changes in internal distortions

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

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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 distortions would have a larger impact in the aggregate world's economy. This is the case of most of the sectors in 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 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 distortions in specific sectors and countries.

Figure 9: World's real GDP elasticity to changes in internal distortions (top 60 markets)

Even more starkly, the importance of the internal distortions can be seen in Figure 9. Here, we rank top 60 elasticities of the world's GDP to a sector in a given country. The largest such internal elasticity - that of China's construction sector (0.0436) has the same size as the elasticity of the world's GDP to all of the external distortions in the United States. More broadly, this graph shows importance of the distortions of individual sectors on the world economy.

Figure 10: World's real GDP elasticity to internal versus external distortions

(a) Internal distortions

(b) External distortions
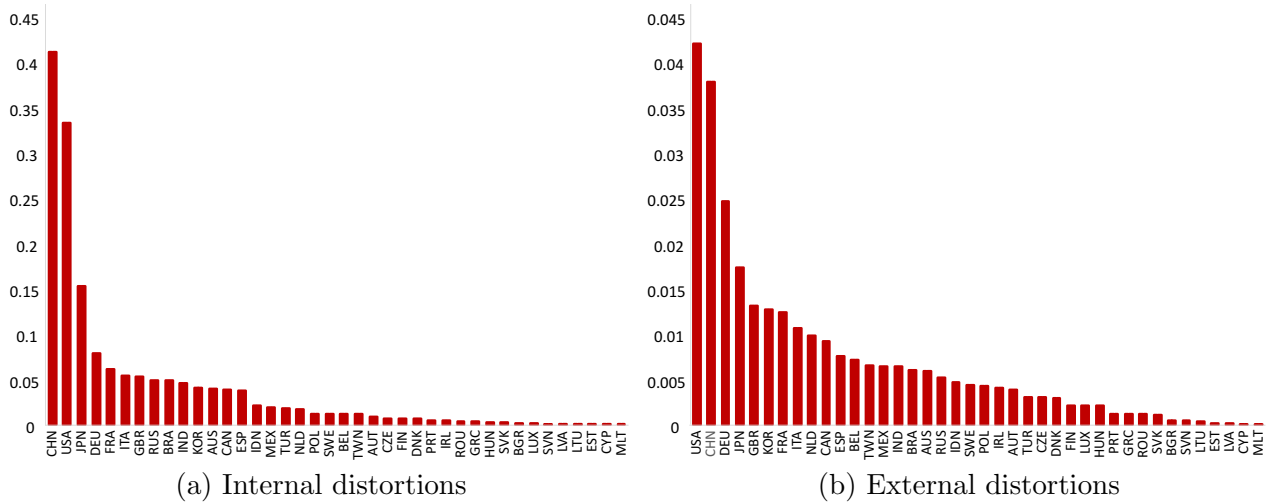
In Figure 10, we compute the world's real GDP elasticity to changes in internal distortions in a given country in Panel (a), and we then compare them with the world's real GDP elasticity to changes in external distortions. From Panel (a), we can see that the largest elasticity is that of China at 0.41, followed by the United States (0.33), Japan (0.15), and Germany (0.08). Panel (b) presents the calculations for the elasticity of world's GDP to external distortions. The largest elasticity is that of the United States at 0.042, followed by China (0.038 percent), Germany (0.025 percent), and Japan (0.017 percent).

Comparing the elasticities with respect to internal versus external distortions, three facts arise. First, note that while the ranking of the elasticities by countries are similar, they are not identical. Second, and more importantly, the elasticity with respect to the internal distortions is an order magnitude larger than that of external distortions.[10] Third,

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[10]In Appendix 3, we also present the normalized elasticity – the elasticity divided by the size of the country's GDP. The ranking differs but the main insight of the much larger quantitative significance of the

for some countries such as Luxembourg, the elasticity to external distortions is larger than the elasticity to internal distortions. The general finding that the elasticity of internal distortions is larger than the elasticity of external distortions can be connected to our findings in the previous section that domestic input-output relations tend to be more important that cross-country input-output relations. This different magnitude between internal versus external elasticities also sheds lights on the potential impact of changes in domestic versus external policy-related distortions.

5.3   Distortions and TFP

In this section we use the sufficient statistics derived in Section 3 to compute the evolution of internal distortions and TFPs for the period of study. Our principal finding is a significant heterogeneity in the growth rate of the distortions and their distribution across countries. We conclude with the computation of the change in global input-output shares and world's real GDP elasticity to the actual changes in domestic distortions over the period 1995-2011.

5.3.1   Internal Distortions

Turning to the analysis of the internal distortions, Figure 11 shows the distribution of the annual rate of growth of internal distortions for the world, and for selected countries. This is an important graph as it shows several notable features. First, there is large heterogeneity in terms of the growth rate of distortions across sectors. For each country there are sectors in which the distortions grew and in which distortions 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.

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


internal elasticities remains.

Figure 11: Distribution of changes in internal distortions in selected countries
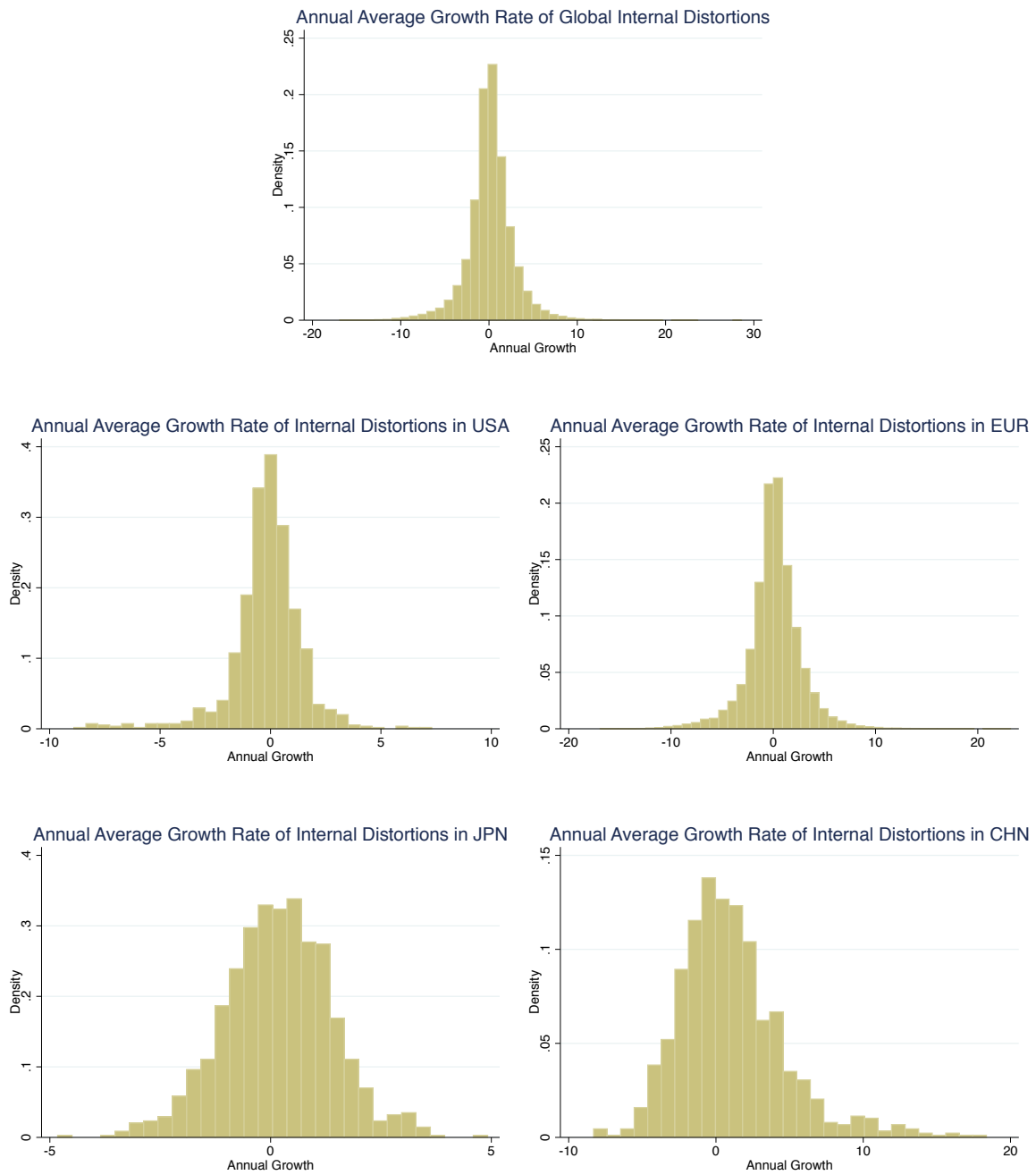
5.3.2 TFP

We now turn to our TFP calculations. As it was clear in Section 4, 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.

Figure 12: World's TFP annual growth rate
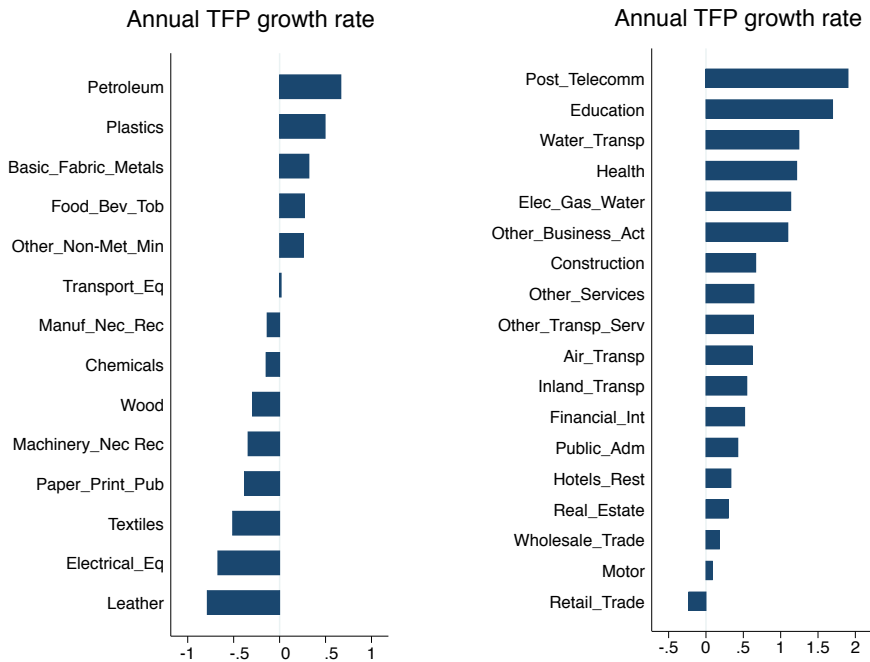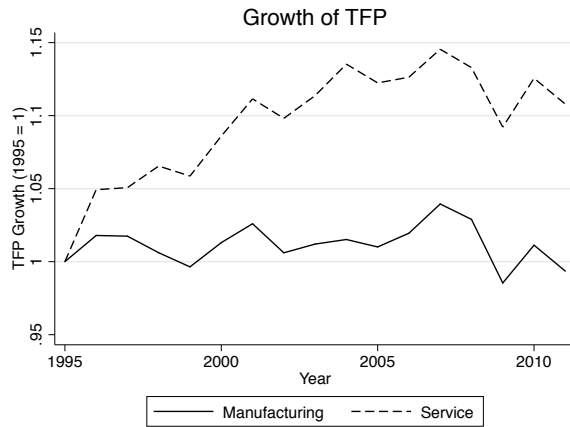
The upper panel in Figure 12 shows the evolution of the TFP in the manufacturing sector and the service sector, using gross output weights to aggregate TFP across industries and countries. The lower panels show the annual growth in TFP in the world across different manufacturing and non-manufacturing sectors. A clear fact from the figure is the higher growth rate in the service sectors than in 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 13 we compare our constructed TFP series for the United States, where we recover the aggregate TFP by using TFP estimates from the agricultural sector from the U.S. Department of Agriculture and from EU_Klems, with the BLS multi-factor 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. We also computed the annual growth in TFP across countries, and find, similar to the changes in internal distortions, significant heterogeneity across sectors and across countries.

Figure 13: U.S. aggregate TFP
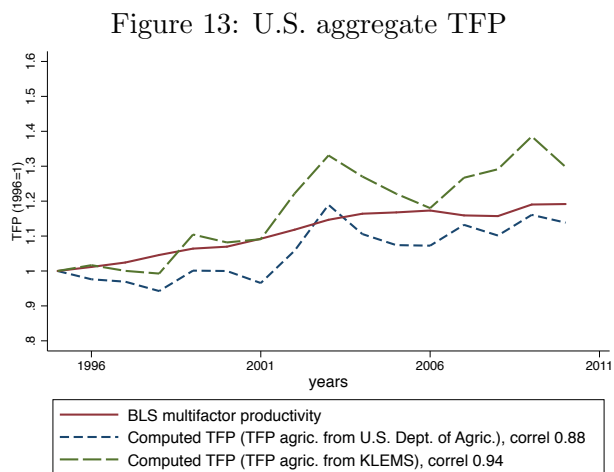
5.3.3 Effects of Actual Changes in Internal Distortions

In this section, we combine the elasticities of the input-output shares and world's GDP with respect to changes in internal distortions, and our computed internal distortions using the sufficient statistics derived in Section 4. 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 distortions over the period 1995-2011.

We start with Figure 14 that shows the change (absolute and percent) in global expenditure shares with respect to the actual changes in internal distortions. In other words, the figure shows how the world's input-output structure would have changed if internal distortions 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 distortions. As a result, we see how the actual changes in distortions 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 distortions 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.[11]

Figure 14: Change in global expenditure shares to actual changes in internal distortions

| (a) Global expenditure shares | (b) Global expenditure shares |
| (absolute changes) | (percentage changes) |

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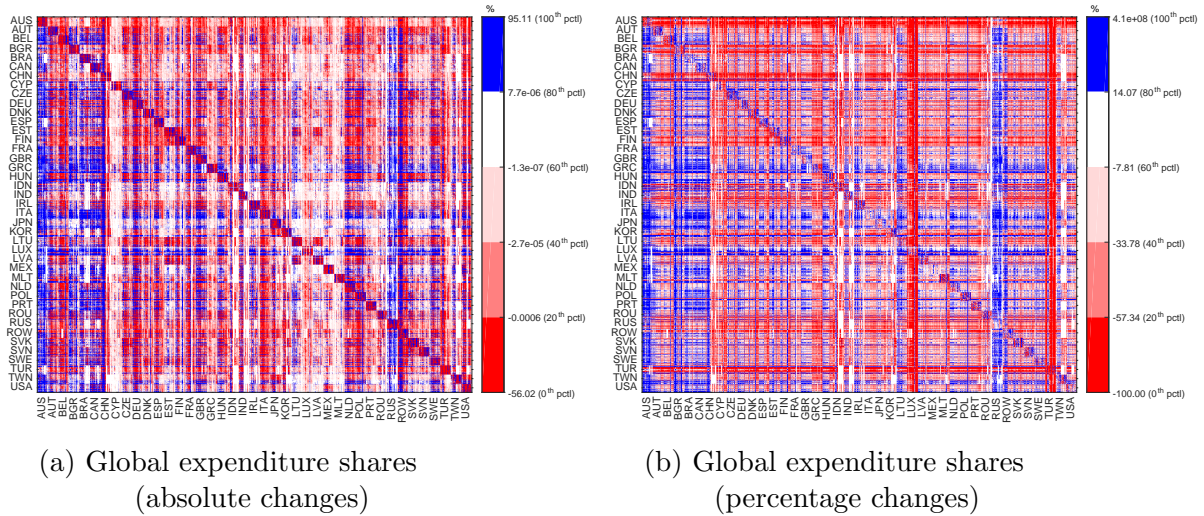
[11]The very large percentage changes at the top percentile on the right panel correspond in general to cases with a very small (close to zero) initial input-output share that experienced significant changes in distortions over 1995-2011. Examples of these outliers are purchases from the metal sector 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.

Figure 15: Growth in world's GDP with respect to actual changes in internal distortions
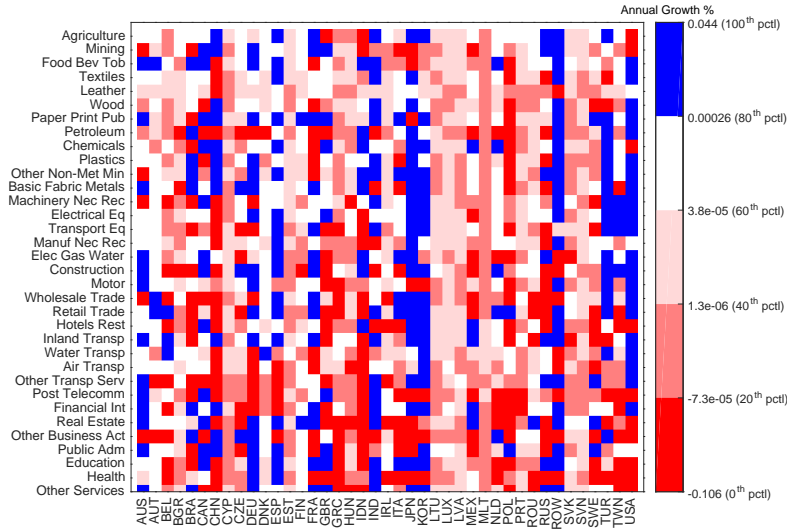
Finally, Figure 15 displays the change in world's GDP with respect to the actual changes in internal distortions. We compute the change in world's GDP by aggregating the change in real wages across countries using each country's GDP as weights. The figure shows that the growth rate in world's GDP to a change in local distortion 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 distortions discussed in Section 5.3.1, and also with the fact that some sectors have become more distorted and other less distorted in some countries relative to others. For instance, lower distortions 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.

6   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 resolve an important issue in the analysis of economies with distortions, namely, how to analytically and empirically separately identify distortions and TFPs in the cases when the input-output relationships may differ across countries. Our finding of significant

heterogeneity in distortions within and across countries implies that the analysis of the aggregate distortions at the country level may be masking the effects of the the disaggregated distortions. Even more importantly, we show how to analytically compute the elasticities of distortions 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 distortions 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 distortions are an order of magnitude larger than those of the external distortions. Finally, we show how the world economy changed due to the evolution of the internal distortions in 1995-2011. We see how the world became more interconnected and how China's rise affected the world economy. 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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Appendix 1: World's input-output elasticities

In this Appendix, we derive the elasticity of the world's input-output structure with respect to changes in distortions and productivities. Totally differentiating the price equations we get:

$$d\log P_{ij} = \sum_{m=1}^{N}\sum_{h=1}^{J}\left[-\tilde{\gamma}_{ijmh}d\log A_{mh} + \tilde{\gamma}_{ijmh}d\log\tau_{ijmh} + (1-\beta)\,\tilde{\gamma}_{ijmh}d\log P_{mh} + \beta\tilde{\gamma}_{ijmh}d\log w_m\right]$$

where

$$\tilde{\gamma}_{isip} \equiv \frac{\gamma_{isip}}{1 - \gamma_{isip}\,(1-\beta)},$$

Let's define P be the vector that contains the log change in prices across all sectors and countries, that is

$$\underset{(NJ\times 1)}{P} = \begin{bmatrix} dlogP_{11} \\ . \\ . \\ dlogP_{1J} \\ . \\ . \\ dlogP_{NJ} \end{bmatrix}$$

Similarly, we define the vectors of log changes in TFPs and distortions as

$$\underset{(NJ\times 1)}{A} = \begin{bmatrix} dlogA_{11} \\ . \\ . \\ dlogA_{1J} \\ . \\ . \\ dlogA_{NJ} \end{bmatrix} \qquad \underset{(NJNJ\times 1)}{\tau} = \begin{bmatrix} dlog\tau_{1111} \\ . \\ . \\ dlog\tau_{111j} \\ . \\ . \\ dlog\tau_{NJ11} \\ . \\ . \\ dlog\tau_{NJNJ} \end{bmatrix}$$

Finally we define the vectors of log changes in input-output shares and wages as

$$
\underset{(NJNJ\times1)}{\Gamma} =
\begin{bmatrix}
dlog\gamma_{1111} \\
. \\
. \\
dlog\gamma_{111j} \\
. \\
. \\
dlog\gamma_{JN11} \\
. \\
. \\
dlog\gamma_{jnjn}
\end{bmatrix}
\qquad
\underset{(NJ\times1)}{\omega} =
\begin{bmatrix}
dlogw_1 \\
dlogw_1 \\
. \\
. \\
dlogw_n \\
dlogw_n
\end{bmatrix}
\qquad
\underset{(NJNJ\times1)}{\tilde{\omega}} =
\begin{bmatrix}
\omega \\
\omega \\
. \\
. \\
\omega \\
\omega
\end{bmatrix}
$$

Therefore, the log change in the expenditure share with respect to changes in distortions is given by

Similarly, let's define the matrices

$$
\Gamma = \theta\tilde{A} - \theta\tau + \Sigma P + \theta\beta\tilde{\omega}
$$

where we define Σ_{ij} to be a $J \times NJ$ matrix that contains the element θ in the column $(j-1) + i \times J$, the element $-\theta(1-\beta)$ in the diagonal, and zeros elsewhere.

Therefore,

$$
\underset{(NJ\times NJ)}{\Sigma} =
\begin{bmatrix}
dlog\Sigma_{11} \\
. \\
. \\
dlog\Sigma_{1J} \\
. \\
. \\
dlog\Sigma_{NJ}
\end{bmatrix}
\qquad \text{and} \qquad
\underset{(NJNJ\times1)}{\tilde{A}} =
\begin{bmatrix}
A \\
. \\
. \\
A \\
. \\
. \\
A
\end{bmatrix}
$$

To solve for the log change in prices, we first define the following matrices

$$
\underset{NJ \times NJ}{Z} = \begin{bmatrix}
0 & \tilde{\gamma}_{1112} & . & . & \tilde{\gamma}_{111J} & . & . & \tilde{\gamma}_{11NJ} \\
\tilde{\gamma}_{1211} & 0 & . & . & \tilde{\gamma}_{121J} & . & . & \tilde{\gamma}_{12NJ} \\
. & . & 0 & . & . & . & . & . \\
\tilde{\gamma}_{1J11} & \tilde{\gamma}_{1J12} & . & . & 0 & . & . & \tilde{\gamma}_{1JNJ} \\
. & . & . & . & . & . & . & . \\
. & . & . & . & . & . & . & . \\
\tilde{\gamma}_{NJ11} & \tilde{\gamma}_{NJ12} & . & . & \tilde{\gamma}_{NJ1J} & . & . & 0
\end{bmatrix}
$$

$$
\underset{NJ \times NJ}{\tilde{Z}} = \begin{bmatrix}
\tilde{\gamma}_{1111} & 0 & . & 0 & . & 0 \\
0 & \tilde{\gamma}_{1112} & . & . & 0 & . & . & 0 \\
. & . & . & . & . & . & . \\
0 & 0 & . & . & \tilde{\gamma}_{NJ11} & . & 0 \\
. & . & . & . & . & . & . \\
. & . & . & . & . & . & . \\
0 & 0 & . & . & 0 & . & . & \tilde{\gamma}_{NJNJ}
\end{bmatrix}
$$

and let $\Omega = I - Z(1 - \beta)$ and $\Upsilon = Z + \tilde{Z}$. Finally, we define the matrix

$$
\underset{NJ \times NJNJ}{\Theta} = \begin{bmatrix}
\tilde{\gamma}_{1111} & . & \tilde{\gamma}_{111J} & . & . & \tilde{\gamma}_{11NJ} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \tilde{\gamma}_{1211} & . & \tilde{\gamma}_{12NJ} & 0 & 0 & 0 & 0 & 0 & 0 \\
. & . & . & . & . & . & . & . & . & . & . & . & . & . & . \\
. & . & . & . & . & . & . & . & . & . & . & . & . & . & . \\
. & . & . & . & . & . & . & . & . & . & . & . & . & . & . \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \tilde{\gamma}_{NJ11} & . & \tilde{\gamma}_{NJNJ}
\end{bmatrix}
$$

$$
\Omega P = -\Upsilon A + \Theta \tau + \beta \Upsilon \omega
$$

and therefore

$$
P = -\Omega^{-1}\Upsilon A + \Omega^{-1}\Theta \tau + \Omega^{-1}\beta \Upsilon \omega
$$

Finally, we can obtain the change in input-output shares as

$$
\Gamma = (\theta \tilde{A} - \Sigma \Omega^{-1}\Upsilon A) + (-\theta 1_{NJNJ \times 1} + \Sigma \Omega^{-1}\Theta)\tau + \Sigma \Omega^{-1}\beta \Upsilon \omega + \theta \beta \tilde{\omega}
$$

where $1_{NJNJ \times 1}$ is a vector of ones of size $NJNJ \times 1$.

Appendix 2: Data appendix (For Online Publication)

This Appendix describes the list of sectors and countries we included in the empirical analysis. The list of sectors is: Agriculture, Hunting, Forestry and Fishing (NACE AtB); Mining and Quarrying (NACE C); Food, Beverages and Tobacco (NACE 15t16); Textiles and Textile Products(NACE 17t18); Leather, Leather and Footwear(NACE 19); Wood and Products of Wood and Cork (NACE 20); Pulp, Paper, Paper , Printing and Publishing (NACE 21t22); Coke, Refined Petroleum and Nuclear Fuel (NACE 23); Chemicals and Chemical Products (NACE 24); Rubber and Plastics (NACE 25); Other Non-Metallic Mineral (NACE 26); Basic Metals and Fabricated Metal (NACE 27t28); Machinery, Nec (NACE 29); Electrical and Optical Equipment (NACE 30t33); Transport Equipment (NACE 34t35); Manufacturing, Nec; Recycling (NACE 36t37); Electricity, Gas and Water Supply (NACE E); Construction (NACE F); Sale, Maintenance and Repair of Motor Vehicles Retail Sale of Fuel (NACE 50); Wholesale Trade and Commission Trade, Except of Motor Vehicles (NACE 51); Retail Trade, Except of Motor Vehicles ; Repair of Household Goods (NACE 52); Hotels and Restaurants (NACE H); Inland Transport (NACE 60); Water Transport (NACE 61); Air Transport (NACE 62); Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies (NACE 63); Post and Telecommunications (NACE 64); Financial Intermediation (NACE J); Real Estate Activities (NACE 70); Renting of M&Eq and Other Business Activities (NACE 71t74); Public Admin and Defense; Compulsory Social Security (NACE L); Education (NACE M); Health and Social Work (NACE N); Other Community, Social and Personal Services (NACE O); Private Households with Employed Persons (NACE P). We drop from the analysis the Private Households with Employed Persons as it presented generally incomplete data. The list of countries is: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Poland, Portugal, Romania, Russia, Slovak Republic, Slovenia, South Korea, Spain, Sweden, Taiwan, Turkey, United Kingdom, United States, and the constructed Rest of the World.

Appendix 3: Normalized elasticities to changes in distortions (For Online Publication)

In this appendix, we present the normalized elasticities of world's real GDP with respect to changes in internal and external distortions, that is, the elasticities are divided by the size of the country's GDP.

Figure 16: World's real GDP elasticity to internal versus external distortions

(a) Internal distortions
(normalized by country i's share in world GDP)

(b) External distortions
(normalized by country i's share in world GDP)