Universidad de San Andrés

Departamento de Economía

Maestría en Economía

Regional Exposure to Trade Shocks: Reconciling Theory and Evidence

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"Exposición Regional a Choques de Comercio: Reconciliando la Teoría y la Evidencia"

Resumen

Una literatura creciente muestra que los choques al comercio internacional pueden tener efectos heterogéneos en las regiones de un país. Esta literatura tiene dos enfoques generales. El primer enfoque es de forma reducida y consiste en hacer regresiones de los cambios en variables regionales en medidas de exposición regional al comercio. La variación en estas medidas de exposición regional se debe principalmente a la variación en la participación del empleo sectorial en todas las regiones. El segundo enfoque estima los modelos de equilibrio general estructural y cuantifica los cambios en los resultados regionales en respuesta a un shock comercial a través de ejercicios contrafácticos. Aquí mostramos que las medidas de exposición de forma reducida no pueden derivarse de un modelo de equilibrio general, incluso si solo se considera el efecto de equilibrio parcial. Utilizando datos brasileños de flujos comerciales intra-país, mostramos que estas diferencias analíticas entre la forma reducida y las medidas teóricas de exposición se traducen en diferencias cuantitativas en las medidas. También mostramos que la correlación de ranking entre las diferentes medidas de exposición regional es sensible al país de origen del shock de costos de importación. Los resultados sugieren tener precaución al usar medidas de exposición de forma reducida para recuperar las elasticidades parciales de los salarios regionales a un choque comercial internacional.

Palabras clave: choques de comercio internacional, salarios regionales, forma reducida, equilibrio general

"Regional Exposure to Trade Shocks: Reconciling Theory and Evidence"

Abstract

A growing literature shows that shocks to international trade can have heterogenous effects across regions within a country. This literature takes two broad approaches. The first approach is reduced-form and consists of regressing changes in regional outcomes on *measures of regional exposure to trade. The variation in these measures of regional exposure is primarily driven by variation in sectoral employment shares across regions. The second approach estimates structural general equilibrium models and quantifies the changes in regional outcomes in response to a trade shock through counterfactual exercises. We show that the reduced-form measures of regional exposure cannot be derived from a general equilibrium model even when only considering the partial equilibrium effect. Using Brazilian data on sub-country trade flows, we show that these analytical differences between the reduced form and theoretical measures of exposure translate into quantitative differences in the measures. We also show that the rank correlation between the different measures of regional exposure is sensitive to the source country of the import cost shock. The results presented caution against relying too heavily on reduced-form exposure measures to recover partial elasticities of regional wages to an international trade shock.*

Keywords: international trade shocks, regional wages, reduced-form, general equilibrium

Códigos JEL: F16, F66, R13

Regional exposure to trade shocks: Reconciling theory and evidence

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August 1, 2019

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A growing literature shows that shocks to international trade can have heterogenous effects across regions within a country. This literature takes two broad approaches. The first approach is reduced-form and consists of regressing changes in regional outcomes on measures of regional exposure to trade. The variation in these measures of regional exposure is primarily driven by variation in sectoral employment shares across regions. The second approach estimates structural general equilibrium models and quantifies the changes in regional outcomes in response to a trade shock through counterfactual exercises. We show that the reduced-form measures of regional exposure cannot be derived from a general equilibrium model even when only considering the partial equilibrium effect. Using Brazilian data on sub-country trade flows, we show that these analytical differences between the reduced form and theoretical measures of exposure translate into quantitative differences in the measures. We also show that the rank correlation between the different measures of regional exposure is sensitive to the source country of the import cost shock. The results presented caution against relying too heavily on reduced-form exposure measures to recover partial elasticities of regional wages to an international trade shock.

1 Introduction

A growing literature shows that international trade does not affect all regions in a country in the same manner. This literature has taken two broad approaches to estimate or quantify the effect of trade shocks, such as a change in tariffs or an increase in foreign productivity, on regional economies. One approach, which we call reduced-form, consists in regressing changes in regional outcomes such as wages, employment, and poverty rates on measures of regional exposure to trade. Although exposure measures can vary across the different research designs, the common feature is that they are calculated as a weighted sum of sectoral country-level shocks, where the weights reflect the relative importance of each sector in regional employment. This implies that the only initial characteristic of regions that drives its sensitivity to a trade shock is its pattern of sectoral specialization. This is the approach pioneered by Topalova (2010) and followed by others, such as Autor et al. (2013) and Kovak (2013). The other approach, which we call quantitative, consists in using general equilibrium trade models to simulate changes in regional outcomes such as welfare or employment after an international trade shock. This is the approach taken by Caliendo et al. (2017) , Galle et al. (2017).

The two approaches differ not only in the methodology they use - one employs reduced-form regressions and the other simulations - but also in the underlying theory. Quantitative approaches are based on standard trade models such as Armington, Krugman (1980), and Eaton and Kortum (2002). In these models, regional economies trade with each other and trade flows follow gravity forces. The impact of a trade shock on regional welfare and incomes is determined in equilibrium and does not have a closed-form representation. In contrast, reduced-form approaches are generally not grounded in trade models. An exception is Kovak (2013) who derives his measure of regional exposure from the specific factors model in Jones (1975). However, the model is not general equilibrium and gravity forces are absent.

In general, the results from the reduced form literature are robust. However, lack of a model from which the relationship between the exposure measure and change in regional outcomes is derived makes it difficult to interpret the results within the context of structural general equilibrium models of international trade.

In this paper, we ask first, if reduced form measures of trade exposure can be derived from the standard general equilibrium trade models under reasonable assumptions. We start with a simple model where the home country consists of many regions and the foreign economy consists of many countries. There are many tradable sectors and a non-traded sector and workers are perfectly mobile across sectors but not allowed to migrate across regions or countries. We focus on changes in regional wages – which in the model are equivalent to changes in regional incomes – as an outcome variable and show that they can be decomposed into a direct effect of an international trade shock and an indirect effect. The direct effect is a partial equilibrium effect, holding constant the endogenous variables in the model. The direct effect depends both on the shock itself but also the initial pattern of trade linkages between a region i, the other regions within the Home country, and foreign countries. The indirect effect is the effect of the international trade shock that operates through endogenous wage changes in all regions. We argue that, by construction, the reduced-form measures of exposure ignore the impact of wage changes in other regions on the wage changes in region i and hence ignore the indirect effect. Thus, empirical measures of exposure can be thought of as trying to capture a partial equilibrium effect of an international trade shock on regional wage changes.

Further, we also find analytical differences between the reduced-form exposure measures and the partial equilibrium effect derived from the model (Direct Effect - DE). The regional variation in the reduced-form measures is driven primarily by variation in sectoral employment shares across regions. In contrast, the variation in the Direct Effect measure is driven by the initial pattern of trade linkages that vary not only across regions but also across the source country of the international trade shock.

Our second question is, do these analytical differences between the Direct Effect measure and reduced-form measures result in quantitatively significant differences in how the reduced-form measures perform in predicting equilibrium wage changes relative to the Direct Effect measure? For this purpose, we take the model to Brazilian data in 1999, treating Brazil as the home country and Brazilian states as regions within the home country. We solve for equilibrium wage changes after an international trade shock using the hat algebra method of Dekle et al. (2008). Then, we compare the coefficients of correlation between the model-based equilibrium wage changes and different measures of regional exposure. We distinguish between two popular types of reduced-form measures. The first one, employment weighted trade cost change (ETC) is based on the measures by Topalova (2010) and Kovak (2013) and uses the actual sectoral shock (for example a trade cost change) and weights it with sectoral employment shares in a region. The second one, based on the measure by Autor et al. (2013), uses the change in sector-wise imports into the home country (Brazil) per worker employed in the sector in the Home country and weights it by the region's sectoral employment share. We refer to this as the employment weighted trade flow change or ETF.

In the quantitative exercises we first consider an increase in the iceberg trade cost of importing from a foreign country into Brazil for all manufacturing sectors. We do this exercise for USA, China and Mexico separately. We find that the correlation between the model-based regional wage changes and the Direct Effect vary with the source country of the import cost shock. We also find that the coefficients of correlation between the wage changes and the empirical exposure measures are not monotonically related to the correlation coefficient of the Direct Effect. That is, it is not the case that empirical measures of exposure exhibit a higher correlation with the counterfactual wage changes when the partial equilibrium effect is relatively larger.

In the second set of exercises we increase the iceberg cost of importing from a specific foreign country into Brazil for each manufacturing sector at a time and solve for the resulting counterfactual equilibrium wage changes. We find that the coefficient of correlation between the equilibrium wage changes and the different measures of regional exposure vary not only across source countries of the import cost shock but also across sector and source country combinations. We also find that reduced-form measures of exposure perform less consistently in predicting the model based wage changes even when compared to the theoretically derived partial equilibrium effect (Direct Effect - DE).

The reduced-form measures (ETC and ETF) and the Direct Effect are different measures of a region's partial equilibrium exposure to an international trade shock. An iceberg import cost shock to only one sector at a time simplifies the Direct Effect measure and the employment weighted trade cost change measure ETC. The ranking over regions provided by these two measures for different source countries of the import cost shock can be compared without having to solve for the counterfactual equilibrium for each sector-source country combination. We calculate the Direct Effect and the ETC measures of exposure for each manufacturing sector specific shock and for each different source country in our data and investigate whether these two measures rank regions in a similar manner. For certain sectors, the rank correlation between the two exposure measures differs widely depending on the source country of the import cost shock and ranges from 0.31 to 0.72. Thus we find that, in certain sectors, by not taking into account the initial pattern of trade linkages as in the Direct Effect, rankings of regional exposure driven solely by sectoral employment shares can be significantly different from those of model-based partial equilibrium effect.

Finally we simulate a reversal of the Brazilian trade liberalization event of the 1990s. Our model is calibrated to Brazilian data in 1999. We take the economy backwards to the tariff levels in 1990 - modeling it as a proportional change in sector-specific iceberg trade costs. We find that the ETC measure exhibits the highest correlation with the model-based wage changes. However, when the shocks are applied to one sector at a time, we find that the correlation between the exposure measures and wage changes varies depending on the specific sector shocked, with the Direct Effect once again performing the most consistently.

We study Brazil for several reasons. First, it provides a suitable environment to study regional responses to trade shocks given that it is a large developing economy, with regions that are heterogeneous in their sectoral activity and their degree of involvement in trade. Second, it has the advantage of having international trade data at the state and product level and, for the year 1999, it also has data on interstate trade, which together with production data it allows us to reconstruct the full trade matrix of Brazilian states with each other and with the rest of the world. Finally, 1999 is an ideal year to study the type of shocks we analyze in this paper given that it is right after the liberalization period of the 1990s which allows to conduct a trade liberalization reversal counterfactual and it is before China's accession to the WTO, which allows us to conduct a China-shock counterfactual.

This paper relates to several strands of the literature. As mentioned above, it speaks to the empirical literature that studies the regional effects of trade using reduced-form designs. A group of studies pioneered by Topalova (2010) use regionally-weighted tariff changes to study the impact of trade on different outcomes such as poverty (Topalova (2010) in India) and wages (Kovak (2013) in Brazil and Hakobyan and McLaren (2016) in the U.S.). In parallel, a related series of studies started by Autor et al. (2013) use regionally-weighted measure of imports per worker to study, for example, the impact of the increase in Chinese import competition outcomes such as employment and wages (Autor et al. (2013) in the U.S., Balsvik et al. (2015) in Norway, Mendez (2015) in Mexico), health (McManus and Schaur (2016) in the U.S.), and crime (Dell et al. (2018) in Mexico), among others.

This paper also speaks to the relatively smaller but growing literature that brings general equilibrium trade models to the data, to quantify the regional effects of trade shocks. Monte (2016) studies the response of local real wages to trade shocks in a model with commuting, Galle et al. (2017) quantifies the distributive effects of the China shock across educational groups and U.S. commuting zones, and Caliendo et al. (2015) quantifies the local employment effects of the China shock in the U.S.

The most closely related papers to ours are Monte (2016) and Adao et al. (2019). Monte (2016) compares predictions from reduced-form approaches to the predictions of general equilibrium models with regional linkages and does so in a model where workers are allowed to commute across regions but where trade costs are uniform across regions in the country, so – unlike in our setting – there is no role for gravity forces driving trade across regions. Adao et al. (2019) develop a model with multiple local labor markets and a methodology to estimate aggregate elasticities that control cross market linkages in labor supply, productivity and trade flows. Using the estimated parameters they compute reduced form elasticities of wages and employment to measures of local exposure. However, the measures of local exposure they use depend on initial trade linkages and are not solely driven by variation in sectoral employment shares across regions.

The rest of the paper is structured as follows. Section 2 describes a general model of inter and intra national trade based on Eaton and Kortum (2002), provides the decomposition of model-based regional wage changes into direct and indirect effects and a detailed description of the partial equilibrium measure of regional exposure, i.e. the direct effect.

Section 3 describes the reduced-form measures of regional exposure. Section 4 presents the outline of the quantitative exercises and describes the data used. Section 5 presents the results of our quantitative exercises and Section 6 concludes.

2 Deriving exposure from existing trade models

We assume a world with two countries, Home (H) and Foreign (F).[1] Home is comprised of N local labor markets or regions. Thus the set of total $N+1$ regions is given by $\mathcal{R} = \{1, 2, \ldots N, F\}$. Labor is the only factor of production and each region $i \in \mathcal{R}$ has a fixed supply of labor L_i. There are K sectors in the economy $k = \{1, 2, \ldots K\}$ and labor is perfectly mobile between sectors of a region. Consumer preferences are homogeneous of degree one and μ_k is the share of income spent on sector k goods.

Under the above assumptions the goods market clearing condition in a region i in each sector k is given by

$$w_i L_i^k = \sum_{n \in \mathcal{R}} \pi_{in}^k \mu_k w_n L_n, \quad k = 1 \ldots K \tag{1}$$

Trade balance further implies that

$$w_i L_i = \sum_{k \in K} \sum_{n \in \mathcal{R}} \pi_{in}^k \mu_k w_n L_n \tag{2}$$

where w_i are wages in region i, L_i^k is total employment in region i and sector k, μ_k is the expenditure share in sector k and π_{in}^k is the bilateral trade share, that is, the share of expenditure that region n allocates on goods from region i and sector k. The left-hand side of Equation 1 is equal to total revenue (which also equals the wage bill) in region i and sector k and the right hand side is equal to the sum of expenditure on goods from region i across all destination markets (including itself).

The conditions above hold for the standard models of international trade mentioned in the Introduction. However, the micro-foundations of the different models give rise to different expressions of the bilateral trade share. In turn, this implies different expressions for the changes in wages in response to trade cost and productivity shocks. We describe below the expressions for the trade shares in three standard models: Armington, Krugman (1980), and Eaton and Kortum (2002).

Armington

[1] For simplicity, in this section we treat the Rest of the World as a single region but the conclusions we reach are not altered by treating it as a group of countries. When taking the model to the data, we work with multiple countries.

Adapting the Armington model to the above setup, each region produces a distinct variety and consumers would like to consume at least some of each variety. Varieties within a sector can be indexed by region. The market for each variety is perfectly competitive and each worker in region i can produce A_i^k units of region i variety in sector k. Consumer preferences are given by an upper level Cobb-Douglas and a lower level CES with elasticity of substitution σ_k. The bilateral trade shares for sector k goods exported from i to n are given by:

$$\pi_{in}^{k,Arm} = \frac{(w_i \tau_{in}^k / A_i^k)^{1-\sigma_k}}{\sum_{r\in\mathcal{R}} (w_r \tau_{rn}^k / A_r^k)^{1-\sigma_k}} \tag{3}$$

where σ_k is the elasticity of substitution between sector k varieties and τ_{in}^k are the iceberg trade costs of shipping a good from i to n.

Krugman (1980)

Krugman (1980) is a monopolistic competition setup with homogeneous firms. Firms in region i sector k have productivity z_i. There is free-entry of firms subject to a fixed cost f_e, which implies a linear relationship between the number of firms and sectoral employment, L_i^k. Consumer preferences are given by an upper level Cobb-Douglas and a lower level CES with elasticity of substitution σ_k. The bilateral trade shares for sector k goods exported from i to n are given by:

$$\pi_{in}^{k,Krug} = \frac{L_i^k \left(w_i \tau_{in}^k / z_i^k\right)^{1-\sigma_k}}{\sum_{r\in\mathcal{R}} L_r^k \left(w_r \tau_{rn}^k / z_r^k\right)^{1-\sigma_k}} \tag{4}$$

Eaton and Kortum (2002)

In each sector, there are a continuum of goods $\Omega_k = [0,1]$. Markets are perfectly competitive. Regions vary in their productivity of each good within a sector $z_i^k(\omega)$, for $\omega \in \Omega_k$. $z_i^k(\omega)$ is drawn independently across countries and goods from a Fréchet distribution with sector specific location parameter A_i^k and sector specific dispersion parameter $\theta_k > 1$.

$$\pi_{in}^{k,\mathrm{EK}} = \frac{A_i^k (w_i \tau_{in}^k)^{-\theta_k}}{\sum_{r\in\mathcal{R}} A_r^k (w_r \tau_{rn}^k)^{-\theta_k}} \tag{5}$$

After showing that the expressions for bilateral trade shares do vary with the micro-foundations of different trade models, we now proceed with the rest of the analysis using the Eaton and Kortum (2002) setup. The analysis for the Armington and Krugman setups can be undertaken analogously.

2.1 Deriving exposure in an Eaton-Kortum model

We are interested in the response of wages to international trade shocks. We focus on two types of shocks: a shock to iceberg trade costs of exporting goods from Foreign to Home ($\hat{\tau}^k_{FH}$) and a Foreign productivity shock ($\hat{A}^k_F$). These are the shocks most frequently analyzed in the empirical literature (Kovak (2013); Autor et al. (2013)). To simplify notation, we denote with $\hat{x} = d\ln(x)$ the logarithm change of x. Starting from the equilibrium condition in equation (2), and totally differentiating yields:

$$\hat{w}_i = \sum_k \sum_n \xi^k_{in} \left(\hat{\pi}^k_{in} + \hat{w}_n \right) \tag{6}$$

where $\xi^k_{in} = \frac{\pi^k_{in}\mu_k w_n L_n}{w_i L_i}$ is the share of total revenue in region i earned from exports to region n in sector k. Further substituting the value of $\hat{\pi}^k_{in}$ into equation (6) we get:

$$\begin{aligned}
\hat{w}_i \;=\;& \underbrace{\sum_k \theta_k \left(\sum_{n \neq R} \xi^k_{in} \pi^k_{Fn} \right) \hat{\tau}^k_{FH}}_{\text{direct effect of } \hat{\tau}^k_{FH}} - \underbrace{\sum_k \sum_n \xi^k_{in} \pi^k_{Fn} \hat{A}^k_F}_{\text{direct effect of } \hat{A}^k_F} \\
& \underbrace{- \sum_k \theta_k \left(\sum_n \xi^k_{in} \left(1 - \pi^k_{in}\right) \right) \hat{w}_i + \sum_k \xi^k_{ii} \hat{w}_i}_{\text{own-region indirect effect}} + \underbrace{\sum_k \theta_k \sum_{h \neq i} \left(\sum_n \xi^k_{in} \pi^k_{hn} \right) \hat{w}_h + \sum_k \sum_{h \neq i} \xi^k_{ih} \hat{w}_h}_{\text{other-region indirect effects}}
\end{aligned} \tag{7}$$

The above equation shows that the wage change in a region i as a result of a country level import cost shock or foreign productivity shock can be decomposed into the direct effect of the shock and the indirect effect. The direct effect is the partial equilibrium effect of an international trade shock on a region's wage changes, holding constant the endogenous variables, i.e. wages in all other regions and economies. The indirect effect is the effect of the international trade shock that operate through endogenous wage changes in all regions. The direct effect is a function of the shock itself and the initial pattern of trade linkages between a region i, the other regions of Home (H) and Foreign (F). The indirect effect depends on the wage changes in all the regions which are endogenous and have to be solved for using the full system of equations.

The empirical measures of exposure commonly used in the literature do not take into account the indirect effects of an international trade shock that arise from endogenous wage changes in all regions. Thus the empirical exposure measures can be interpreted as partial equilibrium measures of a region's sensitivity to an international trade shock. Within the environment of the model, the Direct Effect (DE) is the partial equilibrium effect of the international trade shock. In the next section we further examine the components of the Direct Effect and provide economic interpretations for the same.

2.2 The Direct Effect: A theoretical exposure measure

Equation (7) gives us both the direct and indirect effects of a shock to trade costs or productivity on the equilibrium wages in a region i at $Home$. The Direct Effect in region i (DE_i) can be written as follows:

$$\begin{aligned} DE_i &= \sum_k \theta_k \left(\sum_{n \neq F} \xi_{in}^k \pi_{Fn}^k \right) \hat{\tau}_{FH}^k - \sum_k \left(\sum_n \xi_{in}^k \pi_{Fn}^k \right) \hat{A}_F^k \\ &= \underbrace{\sum_k \theta_k \frac{L_i^k}{L_i} \left(\sum_{n \neq F} \tilde{\xi}_{in}^k \pi_{Fn}^k \right) \hat{\tau}_{FH}^k}_{DE_i^{\tau_{FH}}} - \underbrace{\sum_k \frac{L_i^k}{L_i} \left(\sum_n \tilde{\xi}_{in}^k \pi_{Fn}^k \right) \hat{A}_F^k}_{DE_i^{A_F}} \end{aligned} \tag{8}$$

We focus on the direct effect of a shock to the iceberg trade cost of importing goods from Foreign to Home on the wage changes in region $i \in Home$.

$$DE_i^{\tau_{FH}} = \sum_k \theta_k \frac{L_i^k}{L_i} \left(\sum_{n \neq F} \tilde{\xi}_{in}^k \pi_{Fn}^k \right) \hat{\tau}_{FH}^k \tag{9}$$

The Direct Effect ($DE_i^{\tau_{FH}}$) has three main components. The sector specific trade elasticity (θ_k), the sectoral employment share (L_i^k/L_i) and $\left(\sum_{n\neq F} \tilde{\xi}_{in}^k \pi_{Fn}^k\right)$ which we interpret in greater detail below.

The magnitude of the direct effect is increasing in sector specific trade elasticity θ_k. However, a larger sectoral trade elasticity also implies that for a given change in trade costs, the bilateral trade shares change more. This further implies that the overall general equilibrium effects of a change in trade costs are larger. Thus, even though a higher sectoral trade elasticity makes the absolute magnitude of the direct effect larger, it does not imply that it makes its relative magnitude larger.

The second component of the direct effect is the sectoral employment share in region i. Given all else, the larger the share of workers employed in sector k, the greater the effect of a sector k shock to trade costs on the total counter-factual wage change - both through the direct and indirect effects. The absolute magnitude of the Direct Effect of a sector k shock is increasing in the sector k employment share. However, whether the magnitude of the

Direct Effect relative to the indirect effect increases with the sectoral employment share is unclear. As will be described below, the sectoral employment shares in a region are also an important component of empirical measures of a region's exposure to trade shocks.

The third component of the Direct Effect ($DE_i^{\tau_{FH}}$) is the following expression:

$$\left(\sum_{n\neq F}\tilde{\xi}_{in}^{k}\pi_{Fn}^{k}\right) \qquad \text{where} \qquad \tilde{\xi}_{in}^{k}=\frac{\pi_{in}^{k}\mu_k w_n L_n}{w_i L_i^k}$$

where $\tilde{\xi}_{in}^{k}$ is the share of revenue for region i sector k from exports to region n and π_{Fn}^{k} is the share of sector k expenditure in region n on exports from Foreign F.The term $\tilde{\xi}_{in}^{k}\pi_{Fn}^{k}$ is the product of the sector k revenue share of region i earned from market n times the penetration of Foreign F in market n. This is summed over all relevant destination markets n. This can be thought of as the *effective competition* from F faced by region i sector k in all relevant destination markets n. Note that the set of relevant destination markets depends on the nature of the shock. In the case of a shock to iceberg trade costs of exporting from Foreign F to Home H ($\hat{\tau}_{FH}^{k}$), the set of relevant destination markets for region $i \in H$ are all the other domestic markets $n \in H$.

In the rest of the paper we refer to this term as the *effective competition* faced by region i from Foreign country F. The larger the effective competition faced by domestic region i from Foreign country F, the larger the absolute magnitude of the direct effect. Thus within the model, even when we ignore the changes in overall trade flows as a result of an exogenous shock and focus only on the Direct Effect - the initial intra- and inter-country trade linkages are a component of the Direct Effect ($DE_i^{\tau_{FH}}$). In addition to fundamental sectoral productivities ($A_i^k\ \forall\ i \in \mathcal{R}$), these linkages are in turn crucially governed by gravity forces.

Using the Direct Effect measure of exposure requires sector level inter-country and intra-country trade flows and international trade data at the sub-country level. Data on inter-country trade flows can be obtained quite easily for most countries. However, data on intra-country trade flows and international trade data at the sub-country level is not usually available. In the absence of this, existing literature employs different formulations to construct measures of regional exposure to international trade shocks. The following section describes the most commonly used empirical measures of exposure.

3 Reduced-form measures of exposure

In the following section we describe two measures of regional exposure to international trade shocks from the existing reduced-form literature. Both measures use variation in regional employment composition to estimate the impact of international trade shocks on regional economic outcomes.

The first measure, denoted by ETF, is an employment-weighted trade flow change similar to the one used in Autor et al. (2013)[2]:

$$ETF_i^F = \sum_{k=1}^{K} \frac{L_i^k}{L_i} \left(\frac{\Delta M_{FH}^k}{L_H^k} \right) \tag{10}$$

where (L_i^k/L_i) is the share of labor in region i employed in sector k, ΔM_{FH}^k is the change in total sector k imports from foreign country F to home country H and L_H^k is the total sector k employment in Home country (H).

Similar to the Direct Effect ($DE_i^{\tau_{FH}}$) measure in equation (8), the employment weighted trade flow measure (ETF_i^F) uses sectoral employment shares in a region as weights. However, the $DE_i^{\tau_{FH}}$ measure is additionally composed of the sector specific trade elasticity (θ_k), the size of the trade cost shock $\hat{\tau}_{FH}^k$ and the *effective competition* from foreign country F faced by region i in all relevant destination markets. On the other hand, the ETF_i^F measure considers sector-wise change in imports from Foreign R into Home country (H) as a whole per worker employed in sector k in Home (H).

The variation in the Direct Effect measure across regions is driven both by the pattern of sectoral specialization and the initial set of trade linkages (given by the *effective competition*). On the other hand, the variation in intra-country sensitivity to a trade shock as measured by ETF_i^F is driven primarily by the variation in sectoral employment share across regions. Thus, while using the actual change in imports might help to capture the sector specific trade elasticity and the size of the trade cost shock, the measure does ignore the *effective competition* from foreign country F faced by region i.

In the exercises below we also use an alternative specification of the employment-weighted trade flow change measure:

$$ETF_i^W = \sum_{k=1}^{K} \frac{L_i^k}{L_i} \left(\frac{\Delta M_{WH}^k}{L_H^k} \right) = \sum_{k=1}^{K} \frac{L_i^k}{L_i} \left(\frac{\sum_{F \in \mathcal{W}} \Delta M_{FH}^k}{L_H^k} \right) \tag{11}$$

[2] This measure is derived from an underlying model of international trade that yields a gravity equation. The theoretical expression for counter-factual wage changes is very similar to equation (7) above. However, the paper makes a set of simplifying assumptions to arrive at the final empirical measure used.

where ΔM_{WH}^k is the change in the sector k imports from all countries of the World into the country Home (H). Similar to the ETF_i^F measure, the variation in ETF_i^W measure across regions within a country is primarily driven by the variation in sectoral employment shares.

The second reduced-form measure we focus on, denoted as ETC_i (Rodríguez Chatruc (2016)), is an employment-weighted trade cost change, based on Kovak (2013) and Topalova (2010).

$$ETC_i = \sum_{k=1}^{K} \frac{L_i^k}{L_i} \hat{\tau}_{FH}^k \tag{12}$$

In contrast to the previous empirical measure, the employment-weighted trade cost change (ETC_i) can be derived from a specific factors model that gives rise to wage changes as a weighted average of goods price changes where the weights are the fraction of a region's labor allocated to each sector. Within the context of the specific factors model, this is reduced to a weighted average of the sectoral trade cost changes ($\hat{\tau}_{FH}^k$). Thus, even though this second empirical measure has a direct theoretical foundation, intra-country variation in this measure is once again driven by variation in sectoral employment specialization across regions. This specification arises because all regions face the same world prices that are exogenously given. Since goods' prices are not endogenously determined in the model, a trade liberalization event or a fall in import costs is treated as a proportional change in the world prices faced by all regions within a country.

However, within a general equilibrium model of trade such as Eaton and Kortum (2002), a shock to trade costs results in wage changes that also depend on initial bilateral trade flows (*effective competition*) that follow a gravity structure. While Kovak (2013) does provide a direct theoretical foundation to the exposure measure, the model is not general equilibrium and gravity forces are absent.

4 Empirical Exercise: Outline and Data

4.1 Outline

In the previous section we described two measures of regional exposure to international trade shocks that are widely used in the reduced-form literature. We also compared the measures to the Direct Effect (DE_i^τ) that is derived from a model of international trade based on Eaton and Kortum (2002). We observe that intra-country variation in the reduced-form measures of regional exposure is driven purely by intra-country variation in sectoral employment shares. While the Direct Effect (DE) also has sectoral employment shares, variation across regions is additionally driven by variation across regions in the *effective competition* that they face from the source country of the international trade shock.

However, computing the *effective competition* requires data on intra-country trade flows and trade between domestic regions with Foreign countries which is not usually available. On the other hand, the reduced-form measures described in the previous section require only employment data at the region and sector level and data on tariff changes or international trade flows. The question follows - do these analytical differences between the theoretical measure of exposure (Direct Effect - DE) and the reduced-form measures of exposure result in quantitatively significant differences in each measure's predictions of regions' sensitivity to international trade shocks?

To answer this question, we undertake the following exercise. First, we take the model described in Section 2 to Brazilian data in 1999, treating Brazil as the Home economy with 27 Brazilian states as regions within Home, and 24 countries and a constructed rest of the world as Foreign. Second, we apply different shocks to international trade costs and solve for counterfactual wage changes for the states of Brazil and the Foreign countries in our sample.

We then use the model-generated data to assess the strength of the Direct Effect (DE_i^τ) in predicting the equilibrium wage changes. In other words, we are interested in how much of the variation in the total counterfactual equilibrium wage changes across regions can be explained by variation in the Direct Effect. To understand the importance of the Direct Effect, we calculate beta weights[3] and undertake relative weights analysis.

Recall from equation (7) that the total counterfactual wage changes can be decomposed into the Direct Effect (DE_i^τ) and Indirect Effect (IE_i), which is the sum of the own-region indirect effect and other-regions indirect effect.

$$\hat{w}_i = DE_i^\tau + IE_i$$

We construct the variables DE_i^τ and IE_i from data on the initial equilibrium trade flows and the size of the trade cost shock, and solve for counterfactual wage changes ($\hat{w}_i$). We then convert all the variables into z scores and run the following regression:

$$(\hat{w}_i)^z = \beta_1 \left(DE_i^\tau\right)^z + \beta_2 (IE_i)^z$$

[3]Beta weights are the regression coefficients when both the dependent and independent variables are standardized (converted to z-scores). Therefore, both the dependent and independent variables are measured in standard deviation units. They provide an initial rank ordering of the predictor variable's importance in predicting the dependent variable

the coefficients β_1 and β_2 are the beta weights. They provide an initial rank ordering of the predictor variable's importance in predicting the dependent variable (Nathans et al. (2012)). However, beta weights can be solely relied upon to provide an accurate ordering of the contributions of the independent variables only when they are perfectly uncorrelated with each other (Nathans et al. (2012)). Thus we supplement these calculations with relative weights.

Relative weights is a method of partitioning the R^2 in a multiple regression between the independent variables in the model based on a procedure that addresses the problem of correlations between the independent variables. Our results present both the raw and rescaled relative weights. The raw relative weights sum to the R^2 of the regression and the rescaled relative weights sum to 100. Thus the rescaled relative weights can be interpreted as the percentage of the explained variance of the dependent variable that can be attributed to each independent variable.

We also examine the predictive power of the reduced-form measures of regional exposure with respect to the counter-factual wage changes. We compare the coefficient of correlation between the equilibrium wage changes and the empirical exposure measures with the coefficient of correlation between the equilibrium wage changes and theoretically derived partial equilibrium effect (Direct Effect - DE). Recall that in addition to employment weights, the Direct Effect (DET) also contain the *effective competition* term that takes into account the initial configuration of trade linkages. These exercises allow us to assess whether not taking into account the initial configuration of trade linkages results in quantitatively significant differences in each measure's predictions of regions' sensitivity to international trade shocks.

4.2 Data sources and measurement

In taking the model to the data, 1999 is the initial year for our counterfactual exercises. The Home country is Brazil, which consists of 27 states and the Foreign country consists of 24 countries and a "Rest of the World" aggregate. The set of countries used are the same as those in Caliendo and Parro (2015), listed in Table B1 of the Data Appendix[4].

We combine different data sources to obtain the full matrix of trade flows between Brazilian states and foreign countries for each of the 15 traded industries in our analysis. Data on international (i.e. country-to-country) trade flows is obtained from the World Input-Output database (WIOD) (Timmer et al. (2015)). Data on trade flows between Brazilian states and foreign countries is obtained from ComexStat (MDIC (2018)). Data

[4]More details about the data sources and its processing can be found in Appendix B

on within-country trade flows (i.e. state-to-state) is taken from Vasconcelos and Oliveira (2006). Both Comexstat and WIOD data are available for several years. However, the interstate trade data is only available for 1999. Therefore, all our counterfactual exercises take 1999 as the initial year. Finally, we use data from the Brazilian Institute of Geography and Statistics (IBGE) on total output by sector to calculate trade with self for each state as a residual. We concatenate data from all three sources to ensure consistency in inter-country, inter-state and country-state bilateral trade flows.[5]

The industrial classifications are not uniform across different data sources, so we use different crosswalks to arrive at a final classification of 15 tradable sectors (that include agriculture, mining, and 13 manufacturing sectors) and a non-tradable sector. We use sector specific trade elasticities from Costinot and Rodriguez-Clare (2014). Table B2 in the Data Appendix contains the final list of 15 sectors and the sector specific trade elasticities.

Average ad-valorem tariffs applied by Brazil at the sectoral level for 1990 and 1998 are taken from Kume et al. (2000). Since we do not have reliable tariff data for 1999–the base year for counterfactual exercises–,we assume tariffs in 1999 remained at the same level as in 1998. Finally, we eliminate trade deficits from our data before conducting the counterfactual analysis.

5 Results

The following subsections describe the results of our quantitative exercises. In section 5.1 we increase the iceberg cost of importing from a Foreign country into Brazil for all manufacturing sectors by 1%. We do this for USA, China and Mexico separately. In section 5.2 we increase the iceberg cost of importing from a Foreign country into Brazil by 1% for each manufacturing sector at a time. This exercise is once again undertaken for USA, China and Mexico, treating each one separately as the source country of the import cost shock.

5.1 All manufacturing sectors shock to iceberg import costs

We have calibrated the initial equilibrium of the model using Brazilian data in 1999. In the following section we first increase the iceberg trade costs of importing from a specific Foreign country into Brazil by 1% for all manufacturing sectors. The sectors for

[5]Throughout the paper we only consider trade in goods and assume services are entirely consumed in the region or country where they are produced. Although the WIOD an interstate trade data provide information on services trade, the state-to-couNtry data does not. Therefore, we assign all exports of services to other countries in the WIOD as exports to self.

which trade costs change are: Food, Textile, Wood, Paper, Petroleum, Chemicals, Plastic, Minerals, Metal, Machinery, Electrical, Auto and Other (miscellaneous). We solve for the counterfactual equilibrium wage changes in every region of Brazil ($\hat{w}_i$) following the hat-algebra method of Dekle et al. (2008).

We examine the strength of the Direct Effect in predicting the equilibrium wage changes. We also compare the coefficient of correlation between the Direct Effect and the wage changes with the coefficient of correlation between the wage changes and the reduced-form measures of regional exposure. We do this exercise for USA, China and Mexico. We undertake the exercise for three different countries because we want to investigate whether the performance of the different measures of regional exposure varies with the source country of the import cost shock.

5.1.1 One percent increase in import cost from USA: All Sectors

In this section we increase the iceberg trade costs of importing from USA into Brazil by 1% for all manufacturing sectors. To begin, we are interested in how much of the variation in the model-based equilibrium wage changes across regions can be explained by the Direct Effect. The results in Table 1 below present the beta weights and the raw and rescaled relative weights of the Direct Effect and Indirect Effect.

Table 1: Relative Importance of Direct Effect (USA)

Beta Weights

	Direct Effect	**Indirect Effect**
Beta Weight	1.7940***	1.3426***
Std. Error	(0.0348)	(0.0348)

Relative Weights Analysis

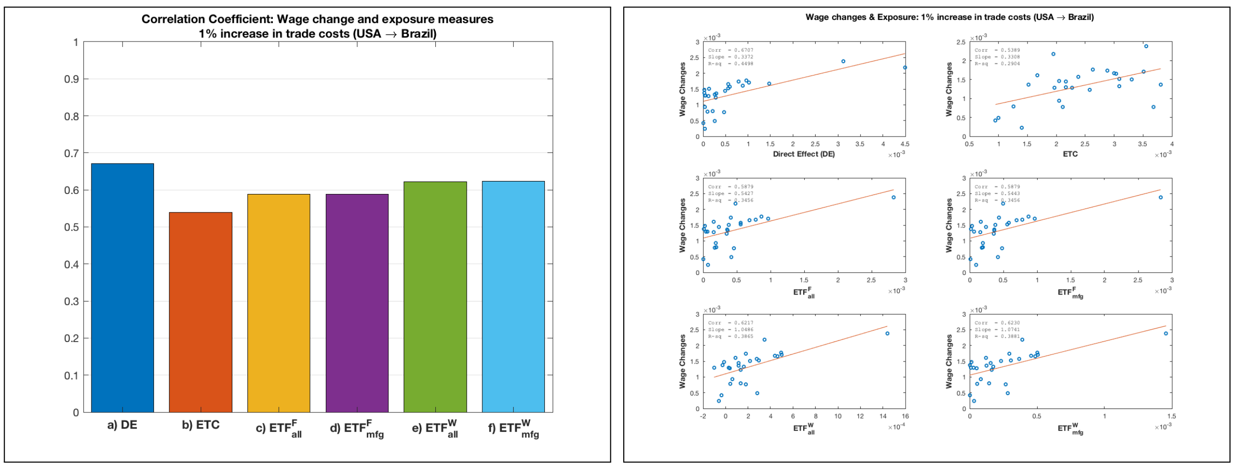
	Direct Effect	**Indirect Effect**
Raw relative weights	0.7082	0.2831
Rescaled Relative Weights	71.441	28.559

This is for a 1% increase in import cost from USA into Brazil

The beta weights indicate that in the case of a 1% increase in import cost from USA to Brazil, the Direct Effect contributes more to predicting the total counterfactual wage changes than the indirect effect. This conclusion holds even when looking at the relative weights. The variation in Direct Effect across regions accounts for 71% of the explained variation in the total counterfactual wage changes. We now compare each exposure measure's predictions of a region's sensitivity to the iceberg import cost shock from USA.

Figure 1 below presents a comparison of the correlation coefficients between the equilibrium wage change and the different measures of regional exposure - the model derived Direct Effect, the employment weighted trade cost change (ETC), the employment weighted trade flow change (ETF^F and ETF^W). There are two versions of each measure of the employment weighted trade flow change, one where we sum over all sectors (ETF^F_{all} and ETF^W_{all}) and the other where we sum over only the manufacturing sectors (ETF^F_{mfg} and ETF^W_{mfg}).

Figure 1: Wage change and exposure measures: Import cost shock from USA



Note that, since the magnitude of the trade cost shock is the same across all manufacturing sectors, the employment weighted trade cost change measure (ETC) for a region i reduces to the share of employment in manufacturing multiplied by the magnitude of the shock. Hence, in this case, the variation in ETC across regions is purely driven by the variation in the manufacturing employment share and doesn't depend on the source of the shock (i.e. the origin country).

Consistent with the results of the beta weights and relative weights analysis, the Direct Effect measure has a correlation of ~ 0.67 with the wage change, higher than that of the other measures. The coefficients of correlation between the empirical exposure measures and the wage changes, while lower than that of the Direct Effect, are all above 0.5.

5.1.2 One percent increase in import cost from China: All Sectors

We are interested in whether the coefficient of correlation between the wage changes and different measures of regional exposure vary with the source country of the import cost shock. In this section we simulate a 1% increase in the iceberg trade costs of importing from China into Brazil for all manufacturing sectors. The results in Table 2 below present the beta weights and the raw and rescaled relative weights of the Direct Effect and Indirect Effect.

Table 2: Relative Importance of Direct Effect (CHN)

Beta Weights

	Direct Effect	**Indirect Effect**
Beta Weight	1.1155***	1.0196***
Std. Error	(0.0032)	(0.0032)

Relative Weights Analysis

	Direct Effect	**Indirect Effect**
Raw relative weights	0.5696	0.4303
Rescaled Relative Weights	56.9676	43.0324

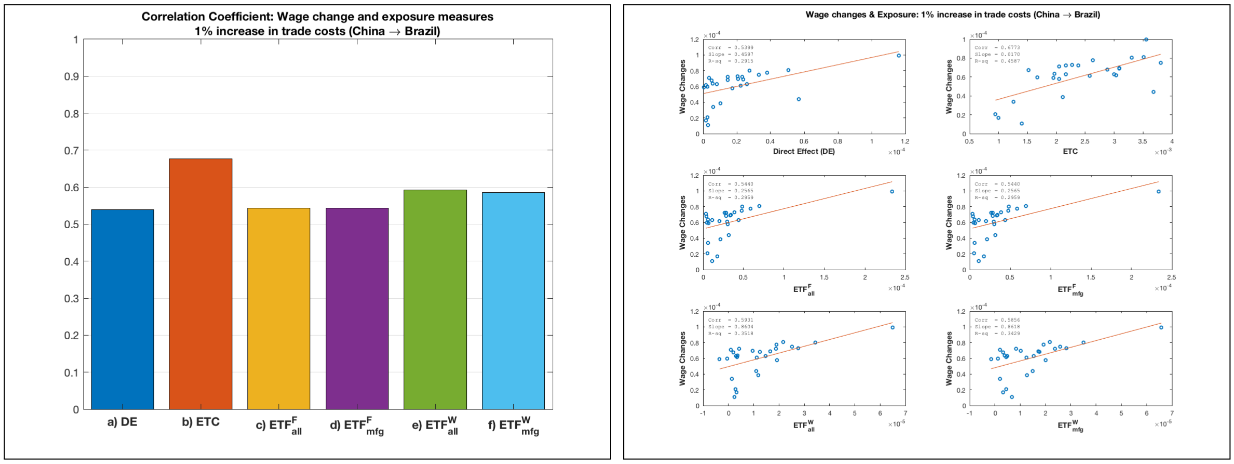
This is for a 1% increase in import cost from China into Brazil

The beta weights indicate that in the case of a 1% increase in import costs from China to Brazil, the Direct Effect contributes more to predicting the counterfactual wage changes than the Indirect Effect. However, the relative weights analysis results indicate that the marginal importance of the Direct Effect is lower in the case of an import cost shock from China than it was in the case of an import cost shock from USA. The variation in the Direct Effect across regions accounts for only about $\sim 57\%$ of the total explained variation in counterfactual wage changes in the case of a import cost shock from China compared to the case of an import cost shock from USA ($\sim 70\%$). Both measures - the beta weights and relative weights - imply that the importance of the Direct Effect in driving variation in the counterfactual wage changes is higher in the case of an import cost shock from USA as compared to an import cost shock from China.

Results in Figure 2 show that the correlation between the Direct Effect and the wage changes is ~ 0.54, lower than in the case of USA as the source country of the import shock (~ 0.67). Thus the correlation seems to be sensitive to the source country of the import cost shock. Note, on the other hand, that the employment weighted trade cost change (ETC) performs much better in the case of China with a correlation of ~ 0.67 with the counterfactual wage change, compared to ~ 0.54 in the case of USA. However, in the case of a uniform import cost shock in all manufacturing sectors, we should be careful about interpreting the employment weighted trade cost change (ETC) measure of exposure. The ETC measure for each region is identical in the two cases of USA and China - the share of employment in manufacturing multiplied by the magnitude of the shock.

In contrast to the ETC measure, the employment weighted trade flow change (ETF)

Figure 2: Wage change and exposure measures: Import cost shock from China



measures do in fact depend on the source country of the import cost shock. ETF^{F}_{all} and ETF^{F}_{mfg} are the employment weighted change in trade flows from the source country of the import cost shock into Brazil. ETF^{W}_{all} and ETF^{W}_{mfg} are the employment weighted change in trade flows from the all countries of the world into Brazil. Changes in trade flows from the World into Brazil also depend on the source country of the import cost shock within the multi-country Eaton Kortum structure. Like the Direct Effect, the coefficients of correlation between the employment weighted trade flow change measures and the equilibrium wage changes are lower in the case of an import cost shock from China as compared to the import cost shock from USA.

5.1.3 One percent increase in import cost from Mexico: All Sectors

In this section we increase the iceberg trade costs of importing from Mexico into Brazil by 1% for all manufacturing sectors. The results in Table 3 present the beta weights and the raw and rescaled relative weights of the Direct Effect and Indirect Effect. The beta weights indicate that in the case of a 1% increase in import costs from Mexico to Brazil, the Direct Effect contributes more to predicting the counterfactual wage changes than the Indirect Effect. The difference in magnitude of the two effects is much larger than in the case of import cost shocks from China or USA. The results of the relative weights analysis show that the Direct Effect accounts for $\sim$ 81% of the explained variation in counterfactual wage changes. This is higher than the re-scaled relative weight of the Direct Effect in the cases of import cost shocks from USA and China ($\sim$ 71% for USA and $\sim$ 57% for China).

Further, as can be seen in Figure 3, the correlation coefficient between the wage change and Direct Effect is very high, at 0.80. The correlation coefficients of the empirical measures of exposure with the wage changes are all above 0.5, but lower than the correlation

Table 3: Relative Importance of Direct Effect (MEX)

Beta Weights

	Direct Effect	Indirect Effect
Beta Weight	1.4331***	0.8529***
Std. Error	(0.0378)	(0.0378)

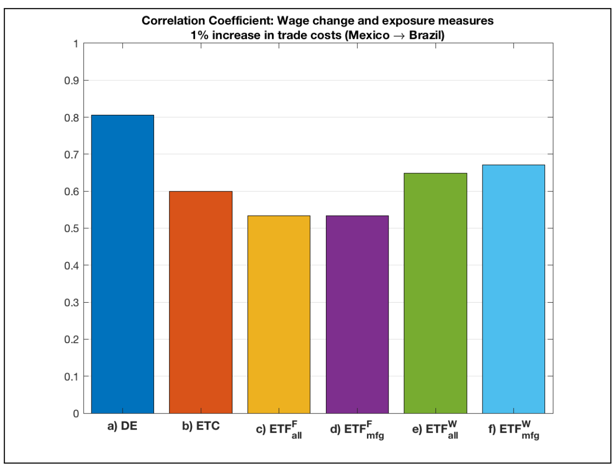
Relative Weights Analysis

	Direct Effect	Indirect Effect
Raw relative weights	0.7969	0.1873
Rescaled Relative Weights	80.9696	19.0303

This is for a 1% increase in import cost from Mexico into Brazil

coefficient for the Direct Effect.

Figure 3: Wage changes and exposure measures: Import cost shock from Mexico



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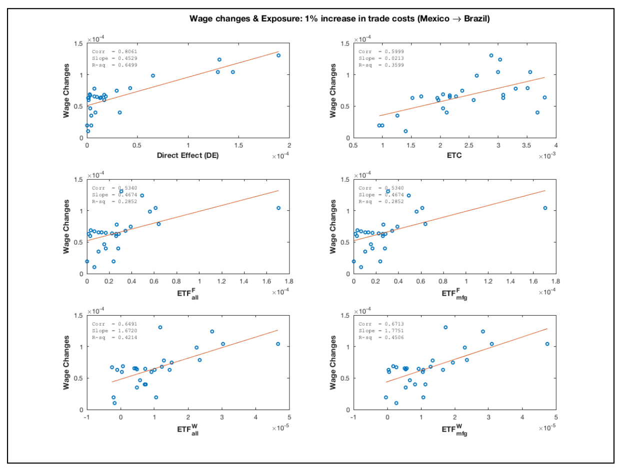


Source m file: TCOSTINC_ALLIND_MEX.m

Comparing across the three different source countries of the import cost shock, the coefficient of correlation between the employment weighted trade flow changes from the World into Brazil (ETF^W_{all} and ETF^W_{mfg}) and wage changes are monotonically related to the coefficient of correlation between the wage changes and the Direct Effect. The correlation coefficients are highest for Mexico, followed by USA and then China. While the employment weighted trade flow changes from the World into Brazil (ETF^W_{all} and ETF^W_{mfg}) do move with the Direct Effect (in terms of correlation coefficients), it is important to further understand what these two measures (ETF^W_{all} and ETF^W_{mfg}) capture and their practical applicability. ETF^W_{all} and ETF^W_{mfg} are the trade flow changes from the World into Brazil. They are calculated using trade flow changes from the initial to the new equilibrium (after the import cost shock). Since they take into account the changes from the World as a whole and not just the source country of the import cost shock, they also capture general equilibrium effects. In fact, they might even have greater predictive power than the Direct Effect, which is a partial equilibrium effect. In practice however, it would be challenging to control for confounding factors when using employment weighted trade flow changes from the World into a particular country as a measure of regional exposure.

Considering all three source countries of the import cost shock, the predictive power of the Direct Effect and the employment weighted trade flows from the source country of the import cost shock (ETF^F) are no longer monotonically related. The coefficients of correlation between employment weighted trade flow changes from the Foreign country (ETF^F_{all} and ETF^F_{mfg}) measures and the counterfactual wage changes are higher in the case of the import cost shock from USA (0.59 for both) than in the case of the import cost shock from Mexico (0.53 for both). For the Direct Effect measure, the correlation coefficient with wage changes is lower in the USA case (0.67) than in the case of Mexico (0.8). This non monotonic relation between the correlation coefficients of the Direct Effect and the ETF^F measures across USA, China and Mexico is nowhere near conclusive evidence of poor performance of reduced-form measures within an Eaton-Kortum structure. Further, the model does not give rise to a closed form solution for equilibrium wage changes so it is not possible to isolate under what conditions we would expect to see the reduced form measures exhibit a high correlation with the counterfactual wage changes. However, it is worth noting that the effects on equilibrium wage changes of an import cost shock from a particular Foreign country depend on the trade linkages between the Foreign country and regions of the Home country. From the maps in Figures C1,C2,C3and C4, we see that the trade linkages of Brazil with USA, China and Mexico are different not only in magnitude but also in their spatial heterogeneity across Brazilian regions. Thus in the model, this would give rise to different equilibrium effects of a 1% increase in iceberg import costs depending on the source country of the import cost shock. This variation would not necessarily be captured by reduced-form measures since their variation is driven by variation in sectoral employment shares across regions. To investigate whether the predictive power of the measures of regional exposure vary not only with the source country of the import cost shock but additionally with the specific industry shocked, in the next subsection we increase the iceberg trade costs of importing from a specific Foreign county into Brazil by 1% for each manufacturing industry at a time and examine the results.

5.2 Sector-wise shock to iceberg import costs

In this subsection we increase the iceberg trade costs of importing from a specific Foreign country into Brazil by 1% for each manufacturing sector at a time and solve for the resulting counterfactual wage changes. We undertake this exercise because we are interested in whether different exposure measures' predictions of a region's sensitivity to an import cost shock additionally vary with the specific sector shocked. Also, an import cost shock to only one sector at a time simplifies the Direct Effect (DE) and the employment weighted trade cost change (ETC) measures of exposure to the cost shock and allows for easier comparisons between the different measures. To illustrate, when there is a change in the iceberg trade cost of importing from foreign country F into Home H only in one sector k, the regional exposure measures are given below:

$$DE_i^{\tau_{FH}} = \theta_k \frac{L_i^k}{L_i} \left(\sum_{n \neq F} \tilde{\xi}_{in}^k \pi_{FH}^k \right) \hat{\tau}_{FH}^k \qquad \forall i \in H$$

$$ETC_i = \frac{L_i^k}{L_i} \hat{\tau}_{FH}^k \qquad \forall i \in H$$

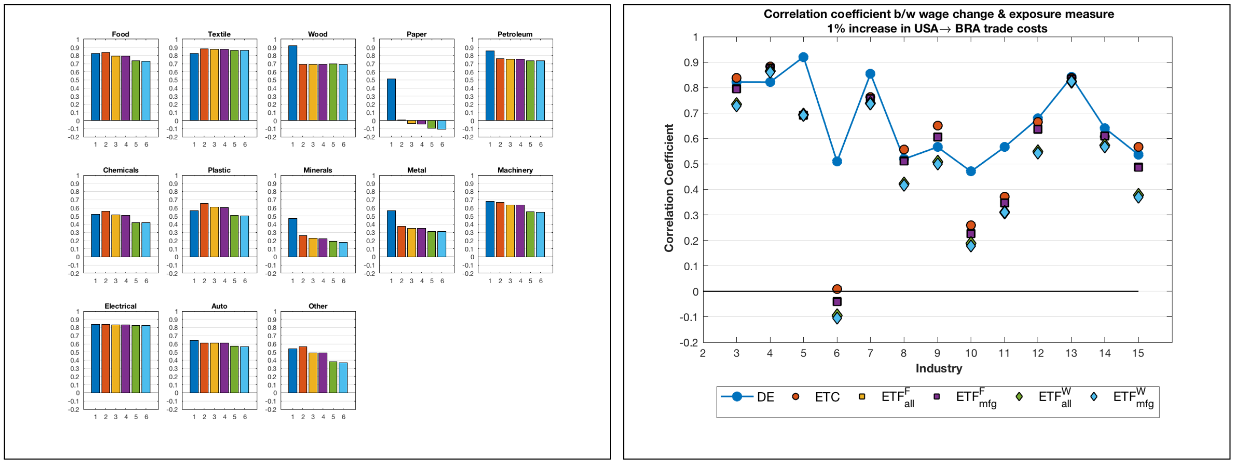
We undertake this exercise again for three different source countries - USA, China and Mexico because we are interested in whether the coefficients of correlation vary not only with the sector shocked but also depend on the source country of the sector specific import cost shock.

5.2.1 Sector-wise one percent increase in import cost from USA

In this section we increase the iceberg trade costs of importing from USA into Brazil by 1% for each manufacturing sector at a time and solve for the resulting counterfactual wage changes. Figure 4 presents the coefficient of correlation between the model-based equilibrium wage changes and the different exposure measures for each industry specific import cost shock. Each bar chart in subfigure 4a presents the coefficient of correlation between the wage changes and different measures of exposure for a given industry specific shock. In subfigure 4b, we have industry codes on the x-axis to indicate the industry that experienced the import cost shock and correlation coefficients on the y-axis. The blue line with markers in subfigure 4b presents the coefficient of correlation between the wage changes and the Direct Effect for each sector specific shock.

The predictive power of all the measures of regional exposure vary depending on the industry that experienced the increase in iceberg trade cost of importing from USA into

Figure 4: Wage Changes and exposure measures: Import cost shock from USA



(a) (b)

Brazil. The Direct Effect performs the most consistently across industries in terms of correlation with regions' sensitivity to sector specific import cost shocks. The coefficient of correlation between the Direct Effect and the counterfactual wage changes range from 0.47 in Non-Metallic Minerals to 0.92 in Wood, products of wood and cork. The correlation coefficient with respect to the Direct Effect is above 0.5 in the case of all industry specific shocks except for Minerals (0.47). A lower coefficient of correlation between the Direct Effect and the counterfactual wage changes indicates that the Indirect Effect has a relatively larger impact on counterfactual wage changes than the Direct Effect.

Since only one sector k is shocked at a time, the employment weighted trade cost change measure (ETC) is now the sector k employment share in region i multiplied by the magnitude of the trade cost shock. Thus the variation in the ETC measure across regions is driven by variation in sector k employment share across regions. The employment weighted trade flow measures ETF is specified as before and takes into account the changes in trade flows in all sectors as a result of the changes in iceberg import cost in a specific sector k.

The coefficient of correlation between Direct Effect and wage changes is higher than the coefficients of correlation between the empirical measures of exposure and the wage changes for eight out of thirteen manufacturing sectors shocked. However, the correlation coefficients for all measures of regional exposure do seem to be monotonically related across industries. The rank-rank correlation between the coefficient of the Direct Effect measure and the coefficients of the reduced-form exposure measures over the sector shocks are at least 0.86.

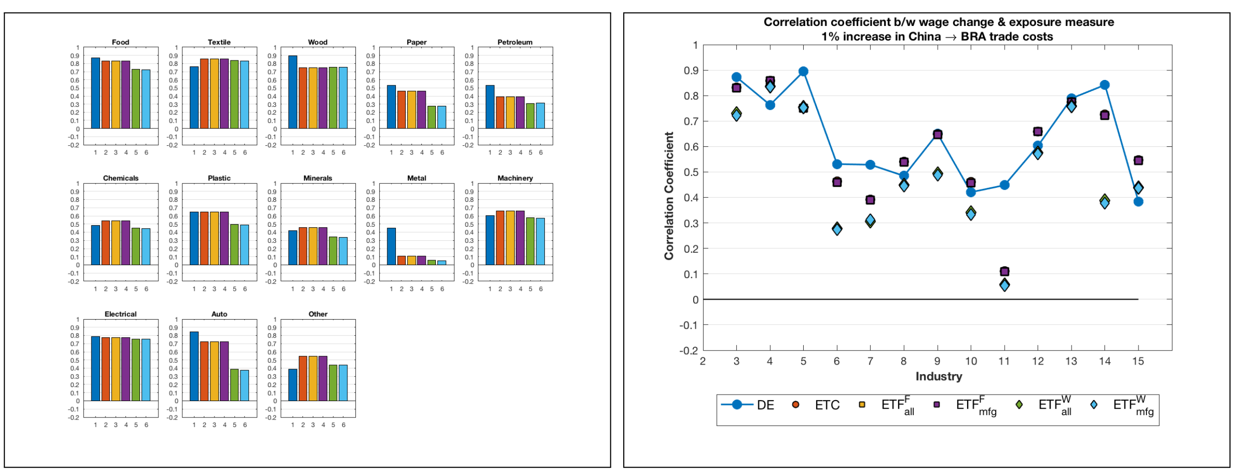
Despite having a similar ordering as the Direct Effect measure over the sector specific shocks as mentioned above, the magnitude of the coefficients of the empirical measures of exposure vary more across industries than that of the Direct Effect measure. The coefficient of correlation between the Direct Effect and the wage changes ranges from 0.47 to 0.92. The coefficient of correlation between wage changes and the employment weighted trade flow changes from USA to Brazil (ETF^F_{all} and ETF^F_{mfg}) ranges from -0.0949 to 0.8648 and -0.1047 to 0.8608 respectively. The reduced-form measures of exposure exhibit particularly low correlation with the model-based wage changes in the case of an import cost shock from USA in Paper, Minerals and Metal, with the lowest coefficient of correlation for Paper.

We are interested in whether the co-movement in the correlation of the wage changes with the Direct Effect measure and the reduced-form measures of exposure across sectors shocked is a general phenomenon or due to the particulars of the source country of the import cost shock. We are also interested in whether the reduced-form measures exhibit low correlation with the counterfactual wage changes in the same sectors (i.e. Paper, Minerals, Metal) irrespective of the source country shocked.

5.2.2 Sector-wise one percent increase in import cost from China

In this section we increase the iceberg trade costs of importing from China into Brazil by 1% for each manufacturing sector at a time and solve for the equilibrium counterfactual wage changes. Figure 5 presents the coefficient of correlation between the equilibrium wage changes and the different measures of regional exposure for each sector specific import cost shock.

Figure 5: Wage Changes and exposure measures: Import cost shock from China



(a) (b)

The predictive power of all measures of regional exposure with respect to the wage changes vary with the sector that experienced the increase in iceberg cost of importing from China. The Direct Effect does not perform across all sectors as well as it did in the case of sector wise shocks from USA. The coefficients of correlation between the Direct Effect and the wage changes range between 0.3843 for Other (Manufacturing nec; Recycling) to 0.8948 for Wood and products of wood and cork, with the coefficients of correlation being less than 0.5 in four out of thirteen sectors - Chemicals and chemical products (0.4846), Minerals (0.4206) and Metal (0.4481) being the other three sectors.

The coefficient of correlation between the Direct Effect and the wage changes is higher than the coefficient of correlation between the reduced-form measures of exposure and the wage changes for eight out of the thirteen manufacturing sectors shocked. Overall, the predictive power of the Direct Effect and the reduced-form measures of regional exposure are monotonically related across sectors. The correlation coefficients of the Direct Effect and the reduced-form measures of exposure with the wage changes exhibit a rank-rank correlation that ranges between 0.6429 (for DE and ETF^{W}_{all}) and 0.7912 (for DE and ETC). The monotonic relationship between the correlation coefficients of the Direct Effect and the reduced-form measures of exposure with the wage changes is weaker in the case of a sector wise import cost shock from China than in the case of an sector wise import cost shock from USA.

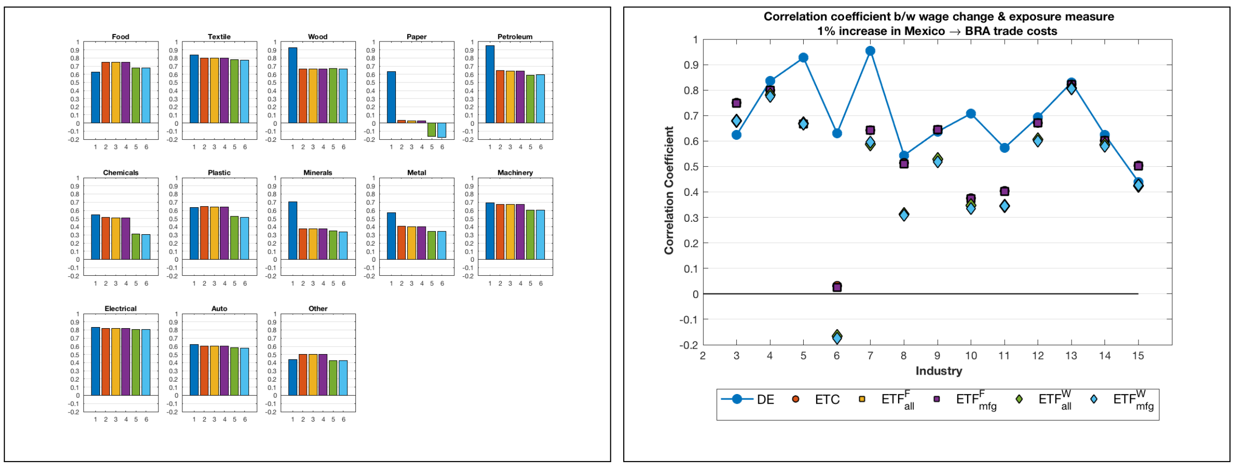
However, similar to the case of USA, we see that the magnitude of the coefficients of the reduced-form measures of exposure are not as consistent across sectors. For instance in the case of the employment weighted trade cost change measure (ETC), the coefficient of correlation ranges from as low as 0.1109 in Metal to 0.8576 in Textiles and Leather. The employment weighted trade flow changes from the World into Brazil in all manufacturing sectors (ETF^{W}_{mfg}) ranges from 0.1093 in Metal to 0.8574 in Textiles and Leather. All the reduced-form measures of exposure perform very poorly in the case of an import cost shock in Metal from China. The coefficient of correlation between the wage changes and all the reduced-form measures of exposure is below 0.11. The coefficient of correlation between the wage changes and the Direct Effect however is approximately 0.44.

On the other hand, in the case of an import cost shock in the same sector, Metal from the USA, the coefficient of correlation between the model based wage changes and the reduced-form measures of exposure are all above 0.3 and the coefficient of correlation between wage changes and the Direct Effect is ~ 0.57. Thus, even for a shock in a specific sector k, the correlation of the measures of exposure with the model based wage changes continue to depend on the source country of the industry shocked.

5.2.3 Sector-wise one percent increase in import cost from Mexico

In this section we increase the iceberg trade costs of importing from Mexico into Brazil by 1% for each manufacturing sector at a time and solve for the resulting counterfactual wage changes. Figure 6 presents the coefficient of correlation between the counterfactual wage changes and the different measures of regional exposure for each sector specific import cost shock.

Figure 6: Wage changes and exposure measures: Import cost shock from Mexico



(a) (b)

The correlation of the different measures of regional exposure with respect to the wage changes vary with the sector that experienced the increase in iceberg trade cost of importing from Mexico into Brazil. The Direct Effect performs the most consistently across sectors in terms of correlation with regions' sensitivity to sector specific import cost shocks, with coefficient of correlation above 0.5 in the case of all sector specific shocks, except for Other (~ 0.44). However, the coefficient of correlation between the Direct Effect and the counterfactual wage changes does vary with the sector shocked and ranges from 0.44 in Other to 0.96 in Coke, refined petroleum and nuclear fuel (Petroleum).

The coefficients of correlation between the Direct Effect and the wage changes is higher than the coefficients of correlation between the reduced-form measures exposure and the wage changes for ten out of the thirteen manufacturing sectors shocked in this exercise. However, the predictive power of the different reduced-form measures of regional exposure have a weaker relationship with that of the Direct Effect in the case of Mexico than in the case of USA or China. The coefficient of correlation with the wage changes for all reduced-form measures of regional exposure are weakly monotonically related with that of the Direct Effect measure across sectors exhibiting a rank correlation ranging between 0.45

(between the DE and ETC coefficients) and 0.56 (between DE and ETF_{all}^{W} coefficients).

The magnitude of the coefficients of correlation between the reduced-form measures of exposure and counterfactual wage changes are not as consistent across sectors as those for the Direct Effect. For instance, in the case of employment weighted trade cost change measure (ETC), the coefficient of correlation with the model-based wage changes ranges from as low as 0.0313 in Paper to 0.8213 in Electrical and optical equipment. It is interesting to note that the ordering of the sectors in which empirical measures perform the worst is same as when the sector specific import cost shocks are from USA - Paper, Minerals and Metal.

5.2.4 Regional exposure rankings across source countries of import cost changes

In the above three subsections we see that the coefficient of correlation between the model-based wage changes and the Direct Effect (DE) measure vary both with the specific industry that experiences an increase in the iceberg import cost and also with the source country of the import cost shock. As stated before, the Direct Effect (DE) measure is the theoretical partial equilibrium effect of a change in iceberg import costs derived from the model. The Direct Effect by definition ignores the indirect effect, that is, the effect on a region's wages that operates through the equilibrium wage changes in all regions. Thus a low coefficient of correlation between the Direct Effect and the equilibrium wage changes implies a greater role for the indirect effect on equilibrium regional wage changes.

The reduced-form exposure measure, employment weighted trade cost change (ETC) by construction also ignores the indirect effect described above. However, from the exercises in sections 5.2.1, 5.2.2 and 5.2.3 we see that the correlation of the Direct Effect (DE) with model-based wage changes and the correlation of ETC exposure measure with model-based wage changes do not always exhibit a strong monotonic relationship. In other words, a large coefficient of correlation between the Direct Effect and the equilibrium wage changes is not necessarily likely associated with a large coefficient of correlation between ETC and the equilibrium wage changes. This is particularly stark in the case of an increase in the cost of importing Metal from China and in the case of an increase in the cost of importing Paper from USA or Mexico.

Considering an increase in the iceberg import cost in only one sector at a time, the Direct Effect (DE) and the employment weighted trade cost change (ETC) measures of exposure are simpler than in the case of an iceberg import cost shock in all manufacturing sectors together. The employment weighted trade flow measures remain the same as they are the weighted sum of the actual change in trade flows across all sectors as a result of the shock to iceberg import costs in even one sector. When there is a change in the iceberg trade cost of importing from Foreign country F into Home H in only sector k ($\hat{\tau}_{FH}^{k}$), the Direct Effect and employment weighted trade cost shock are reduced to:

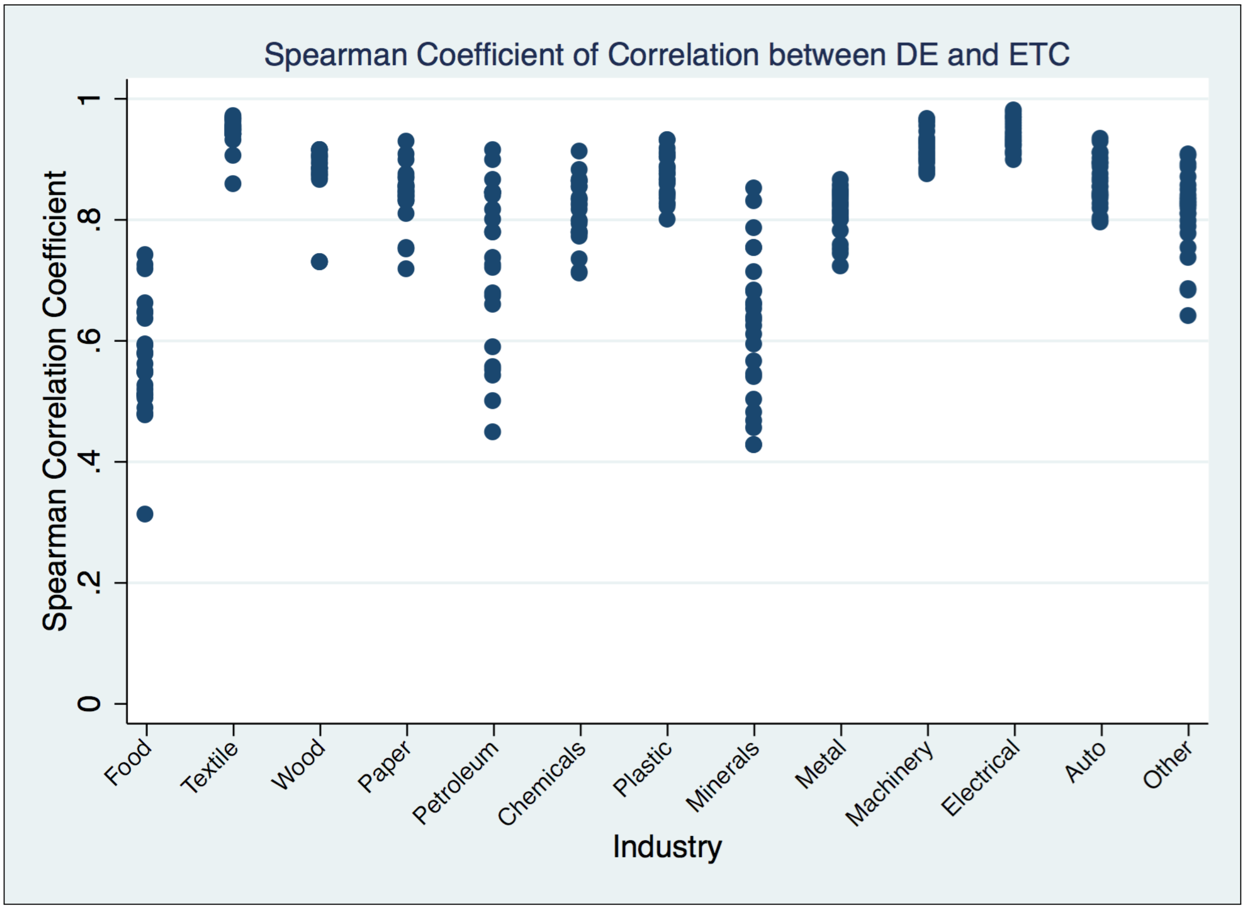
$$DE_i^{\tau_{FH}} = \theta_k \frac{L_i^k}{L_i} \underbrace{\left(\sum_{n \neq F} \tilde{\xi}_{in}^k \pi_{Fn}^k \right)}_{\text{Effective Competition}} \hat{\tau}_{FH}^k \tag{13}$$

$$ETC_i = \frac{L_i^k}{L_i} \hat{\tau}_{FH}^k \tag{14}$$

The variation in the ETC measure across regions is driven solely by variation in employment shares. In fact, when there is an import cost shock to only one sector k, the ETC measure of regional exposure to the import cost shock is larger, the larger the industry k employment share in a region. On the other hand, the Direct Effect measure of a region's sensitivity to an import cost shock in only one sector k is not solely determined by the sector k employment share in a region. As seen from equation (13), the Direct Effect measure includes an additional component, the *effective competition* from F faced by region i sector k in all relevant destination markets n.

While the analytic differences in the two measures can be seen from equations (13) and (14) above, it is unclear whether this translates to quantitatively significant differences in how the two measures order regions in terms of their exposure to a change in iceberg import costs. The Direct Effect measure orders regions according to their partial equilibrium exposure to an iceberg import cost change. The question now is whether the ETC measure, even without taking into account the variation across regions in the *effective competition* faced from a Foreign country F, gives rise to an ordering of regions similar to that provided by the Direct Effect measure. The advantage of comparing the rankings over regions provided by these two measures is that, unlike the employment weighted trade flow change measures (ETF), the DE and ETC measures can be constructed without having to solve for the counterfactual equilibrium for each sector-source country combination. We calculate the Direct Effect (DE) and ETC measures of exposure for each sector specific shock and for each different source country in our data. We have a total of 24 Foreign countries and one constructed rest of the world in our data. The complete list is given in Table B1 in the Data Appendix. For each industry-source country combination, we calculate the rank correlation (Spearman Correlation Coefficient) between the Direct Effect (DE) and the employment weighted trade cost (ETC) measures of regional exposure. The results are in Figure 7 below. The x-axis indicates the industry that experienced a shock to iceberg import cost. Each point on the scatter corresponds to a different source country of the import cost shock. For some industries, such as Plastic and Electrical, the

Figure 7: Rank Correlation of DE and ETC exposure measures by industry and source country



rank correlation between the exposure measures is similar across source countries of the import cost shock. For instance, in Plastic, the rank correlation between the two exposure measures ranges from ~ 0.80 in the case of an import cost shock from South Korea to ~ 0.92 in the case of China. In Electrical the rank correlation between the two exposure measures ranges from ~ 0.90 in the case of an import cost shock from Turkey to ~ 0.98 in the case of France.

However, the ordering over regions' exposure given by the DE and ETC measures do not consistently exhibit similar correlation across the source countries of the import cost shock. In Food, Beverages and Tobacco (Food) the rank correlation between the two exposure measures differs a lot across source countries of the import cost shock. The rank correlation is quite low, at ~ 0.31, when the source country of the import cost shock is India and is approximately ~ 0.72 when the source country is the USA. In the case of non metallic minerals, the rank correlation between the two measures ranges from 0.43 when the source country of the import cost shock is Indonesia to 0.85 when the cost shock is in products imported from Spain.

Thus, the analytical differences in the DE and ETC measures of exposure as seen in equations (13) and (14), when taken to the data in the case of some sector specific shocks translate into significant differences in how the two measures order regions' exposure to an iceberg import cost shock. When examining the Pearson Correlation Coefficient between the two measures of regional exposure (DE and ETC), there is an even larger variation in the correlation coefficients across the source countries of the import cost shock (See Figure C5 in the Results Appendix). We see that in some cases, by not taking into account the *effective competition* that a region i faces from a Foreign country in the relevant destination markets, rankings of regional exposure driven solely by the industry employment shares do not always capture the partial equilibrium exposure of a region to a trade cost shock as determined within a structure based on the model described in Section 2.

5.3 Brazilian Trade Liberalization Event

Until now the results have focused on comparing the correlation between different exposure measures and counterfactual equilibrium wage changes in response to a simulated one percent increase in the iceberg cost of importing from a particular Foreign country into Brazil. However, empirical measures of exposure have been used to study regional sensitivity not only to bilateral trade shocks, but also to multilateral trade shocks, like trade liberalization events. In the 1990s Brazil underwent a massive trade liberalization process. Between 1990 and 1998, import tariffs fell by 52% on average across all manufacturing industries[6]. As mentioned before, we calibrate the initial equilibrium of our model using Brazilian trade data in 1999. We can thus use our model to simulate a reversal of the trade liberalization event and calculate the counterfactual equilibrium wage changes. This exercise has two advantages. This is the first step to future work that compares the wage changes in different regions of Brazil as predicted by the model to the actual wage changes in Brazil between 1990 and 1998. Secondly, this exercise allows us to compare the predictive power of different measures of exposure and how different measures order regions according to their exposure to a trade shock in the case where the Direct Effect (DE) captures the effective competition that a region i faces in all destination markets n, not only from one particular Foreign country F but from all foreign countries that trade with Brazil.

[6] See Kovak (2013) and Kume et al. (2000) for details of the trade liberalization process. The tariffs in 1990 and 1998 for each of the 15 industries are given in Table B3.

5.3.1 Brazilian trade liberalization (reversed): All Industries

In this section we undertake the reversal of the Brazilian trade liberalization. As before, we have calibrated the initial equilibrium to Brazilian data in 1999. We do not have reliable tariff data for 1999, the base year of the initial equilibrium. We assume tariffs in 1999 remained at the same level as in 1998. We then simulate the reversal of the trade liberalization event - taking the economy backwards from the tariff levels in 1998 to the tariff levels in 1990. However, we do not incorporate this as a tariff change. We instead model it as a proportional change in sector specific iceberg trade costs.

Table 4: Relative Importance of Direct Effect: Trade liberalization (reversed)

Beta Weights

	Direct Effect	Indirect Effect
Beta Weight	0.9723***	0.7390***
Std. Error	(0.0941)	(0.0941)

Relative Weights Analysis

	Direct Effect	Indirect Effect
Raw relative weights	0.5738	0.2585
Rescaled Relative Weights	68.9369	31.0631

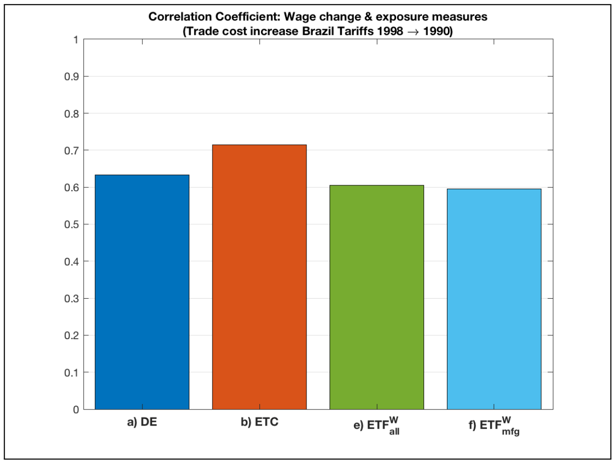
This is for a reversed trade liberalization even

The results in Table 4 present the beta weights and the raw and rescaled relative weights of the Direct Effect and Indirect Effect in this trade liberalization exercise. The beta weights indicate that in this case, the Direct Effect contributes more to predicting the counterfactual wage changes than the Indirect Effect. Consistent with the beta weight ranking, the Direct Effect accounts for $\sim 69\%$ of the explained variation in counterfactual wage changes.

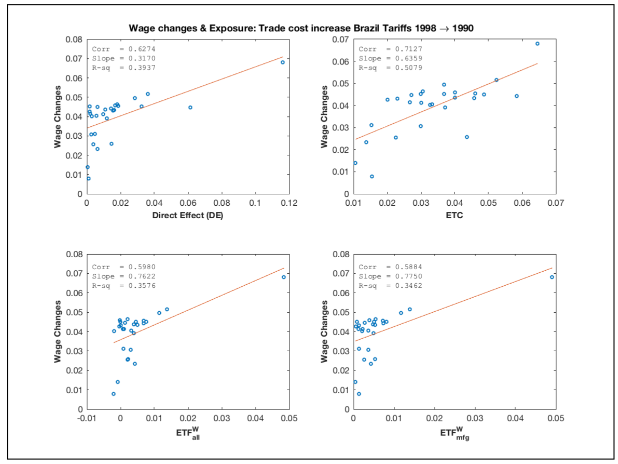
Figure 8 presents the coefficient of correlation between the counterfactual wages and the different measures of regional exposure. Since there is a change in the iceberg cost of importing from all countries into the world, the set of source countries when constructing the ETF^F_{all} and ETF^F_{mfg} measures are all the countries of the world. Thus we have that, for this case, ETF^F_{all} and ETF^F_{mfg} are the same as ETF^W_{all} and ETF^W_{mfg} respectively. We only present the results for ETC^W_{all} and ETF^W_{mfg} measures.

The correlation coefficient is above 0.5 for all measures of regional exposure. The employment weighted trade cost change measure (ETC) exhibits the highest correlation with the counterfactual wage changes with a correlation coefficient of 0.72. In the trade

Figure 8: Wage changes and exposure measures: Trade liberalization event (reversed)



Source m file: TRDLIB_ALLIND.m



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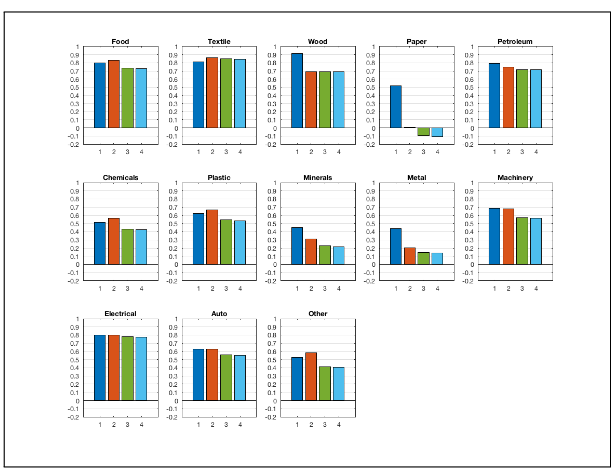
liberalization exercise the variation in ETC across regions of Brazil is no longer purely driven by the share of employment in manufacturing as a whole. Since the trade cost changes vary across sectors, variation in the ETC measure is driven by variation in sectoral employment shares.

5.3.2 Sector-wise trade liberalization (Reversed)

In this section we undertake the reversal of the Brazilian trade liberalization except that that we apply the trade cost shock to one sector at a time. Figure 9 presents the coefficient of correlation between the counterfactual wages and the different measures of regional exposure for each sector-specific import cost shock.

Figure 9: Wage Changes and exposure measures: Import cost shock from Mexico



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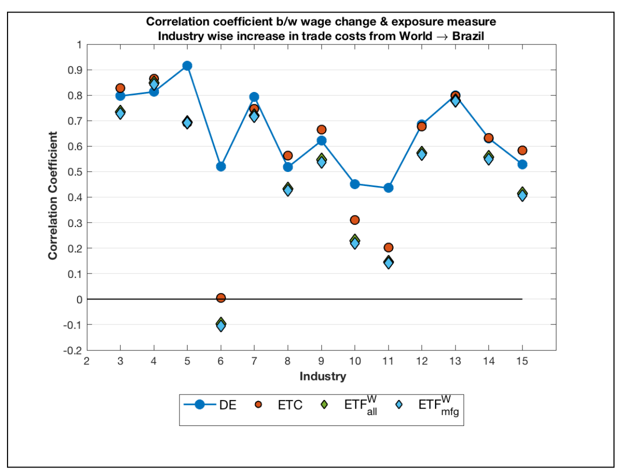

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The primary difference between this and the exercises in section 5.2 is that here there is an increase in the iceberg cost of importing from all foreign countries of the world instead of just one specific Foreign country. Thus the Direct Effect measure now takes into account the effective competition that a region i faces from all Foreign countries.

The predictive power of all the measures of regional exposure once again vary depending on the industry that experienced the increase in the iceberg trade cost of importing into Brazil. The coefficient of correlation between the counterfactual wage changes and the Direct Effect range from ~ 0.44 in Basic and fabricated metals (Metal) to ~ 0.92 in Wood and products of wood and cork. The correlation between the Direct Effect and equilibrium wage changes is less that 0.5 in only two out of the thirteen manufacturing industries.

However, for each industry specific shock the ordinal rankings over regions in terms of exposure to the shock provided by the DE and ETC measures are similar. The rank correlation between the Direct Effect (DE) and the employment weighted trade cost change (ETC) measures vary from ~ 0.70 in industry Food, beverages and tobacco to 0.97 in industry Electrical and optical equipment.

6 Conclusion

This paper focuses on the growing literature that studies how shocks to international trade can have heterogeneous effects across regions within a country. In particular, we seek to understand whether results from the two broad approaches taken by the literature are compatible with each other.

In the reduced form approach, variation in regional exposure to a trade shock is driven primarily by variation in sectoral employment shares across regions. On the other hand, a partial equilibrium measure of regional exposure grounded in a general equilibrium model of trade not only depends on the sectoral employment shares but also on the initial pattern of trade linkages between regions - i.e. the *effective competition* that a region faces from the source country of the trade shock. We show that these analytical differences in the two types of exposure measures translate into quantitative differences in the measures' correlation with model-based equilibrium wage changes in response to a trade cost shock. Even when we undertake a comparison of the ordinal rankings regional exposure to a trade shock provided by the two measures, we find that the correlation between the rankings is sensitive to the source country of the import cost shock. We interpret our results as indicative of a disconnect between the two approaches in the literature, and not an indictment of either. The results presented caution against indiscriminately relying on reduced-form exposure measures to recover partial elasticities of regional wages to a shock to international trade.

Our analysis has some limitations. First, we focus on Brazil but our results may not hold in other countries, where regional variation in sectoral composition and in trade linkages is different. Second, we only consider linkages in final goods' trade but we do not consider that regional economies are linked also by trade in intermediates and by internal migration. Although it is likely that adding these other linkages would generate an even higher disconnect between reduced form-measures of exposure and model-derived ones, we do not formally prove this. Finally, we focus on a single outcome, wages, whereas the literature has also focused on employment. We do this to keep the analysis as parsimonious as possible, to show that even in a simple environment this disconnect between measures emerges. We therefore leave for future research the analysis of other types of linkages between regions and of other labor market outcomes.

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A Theory Appendix

A.1 Deriving Wage Changes

Goods market clearing and trade balance implies

$$w_i L_i = \sum_{k \in K} \sum_{n \in \mathcal{R}} \pi_{in}^k \mu_k w_n L_n \tag{A.1}$$

Totally differentiating equation (A.1) and dividing both sides by $w_i L_i$ we get:

$$\begin{aligned}
\tfrac{w_i dL_i + L_i dw_i}{w_i L_i} &= \frac{1}{w_i L_i} \sum_k \sum_n \left(\mu_k \pi_{in}^k w_n L_n \frac{d\pi_{in}^k}{\pi_{in}^k} + \mu_k \pi_{in}^k w_n L_n \frac{dw_n}{w_n} \right) \\
\Rightarrow \quad \hat{w}_i &= \frac{1}{w_i L_i} \sum_k \sum_n \left(\mu_k \pi_{in}^k w_n L_n \hat{\pi}_{in}^k + \mu_k \pi_{in}^k w_n L_n \hat{w}_n \right) \\
\Rightarrow \quad \hat{w}_i &= \sum_{k \in K} \sum_{n \in \mathcal{R}} \xi_{in}^k \left(\hat{\pi}_{in}^k + \hat{w}_n \right) \text{ where } \xi_{in}^k = \frac{\pi_{in}^k \mu_k w_n L_n}{w_i L_i}
\end{aligned}$$

We now differentiate π_{in}^k:

$$\begin{aligned}
\pi_{in}^k &= \underbrace{\frac{A_i^k (w_i \tau_{in}^k)^{-\theta_k}}{\sum_{l \in \mathcal{R}} A_l^k (w_l \tau_{ln}^k)^{-\theta_k}}}_{D} \\
\hat{\pi}_{in}^k &= \frac{1}{\pi_{in}^k} \frac{1}{D} \left[(w_i \tau_{in})^{-\theta_k} dA_i^k + A_i^k (\tau_{in}^k)^{-\theta_k} (-\theta_k) w_i^{-\theta_k - 1} dw_i - \theta_k A_i^k (w_i)^{-\theta_k} (\tau_{in}^k)^{-\theta_k - 1} d\tau_{in}^k \right] \ldots \\
&\quad - \frac{1}{\pi_{in}^k} \frac{1}{D^2} \left[A_i^k (w_i \tau_{in}^k)^{-\theta_k} dD \right] \\
dD &= \left[\sum_l A_l^k (w_l \tau_{ln}^k)^{-\theta_k} \right] \\
&= \sum_l \left\{ (w_l \tau_{ln}^k)^{-\theta_k} dA_l^k + A_l^k (\tau_{ln}^k)^{-\theta_k} (-\theta_k) w_l^{-\theta_k - 1} dw_l + A_l^k w_l^{-\theta_k} (-\theta_k) (\tau_{ln}^k)^{-\theta_k - 1} d\tau_{ln}^k \right\}
\end{aligned}$$

Substituting dD into expression for $\hat{\pi}^k_{in}$ we get:

$$\begin{aligned}
\hat{\pi}^k_{in} &= \frac{1}{\pi^k_{in}}\left\{\pi^k_{in}\hat{A}^k_i - \theta_k\pi^k_{in}\hat{w}_i - \theta_k\pi^k_{in}\hat{\tau}^k_{in} - \pi^k_{in}\frac{dD}{D}\right\} \\
\hat{\pi}^k_{in} &= \frac{1}{\pi^k_{in}}\left[\pi^k_{in}\hat{A}^k_i - \theta_k\pi^k_{in}\hat{w}_i - \theta_k\pi^k_{in}\hat{\tau}^k_{in} - \sum_{l\in\mathcal{R}}\left\{\pi^k_{in}\pi^k_{ln}\hat{A}^k_l - \theta_k\pi^k_{in}\pi^k_{ln}\hat{w}_l - \theta_k\pi^k_{in}\pi^k_{ln}\hat{\tau}^k_{ln}\right\}\right] \\
\Rightarrow \quad \hat{w}_i &= \sum_k\sum_n \xi^k_{in}\left\{\hat{w}_n + \hat{A}_i - \theta_k\hat{w}_i - \theta_k\hat{\tau}^k_{in} + \sum_{l\in\mathcal{R}}\left(\theta_k\pi^k_{ln}(\hat{w}_l + \hat{\tau}^k_{ln}) - \pi^k_{ln}\hat{A}^k_l\right)\right\} \quad \forall\ i\in\mathcal{R}
\end{aligned}$$

Consider only domestic wage changes, that is $i \in$ Home and $\forall\ n \in R$, and set $\hat{\tau}^k_{il} = 0\ \forall\ i,l \in$ Home:

$$\begin{aligned}
\hat{w}_i &= \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\hat{w}_n + \underbrace{\sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\hat{A}^k_i}_{=0\ \forall\ i\in\text{Home}} - \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\hat{w}_i - \sum_{k\in K}\theta_k\xi^k_{iR}\hat{\tau}^k_{iR} + \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\ldots \\
&\ldots\left[\sum_{l\in\mathcal{R}}\theta_k\pi^k_{ln}\hat{w}_l\right] + \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\left\{\sum_{l\neq R}\theta_k\pi^k_{ln}\hat{\tau}^k_{ln} + \theta_k\pi^k_{Rn}\hat{\tau}^k_{Rn}\right\} - \underbrace{\sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\left[\sum_{l\in\mathcal{R}}\pi^k_{ln}\hat{A}^k_l\right]}_{\text{Recall } \hat{A}^k_l=0\ \forall\ l\in\text{Home}}
\end{aligned}$$

Imposing $\hat{A}^k_i = 0\ \forall\ k \in K$ and $i \in$ Home and $\hat{\tau}^k_{ln} = 0\ \forall\ l,n \in$ Home:

$$\begin{aligned}
\hat{w}_i &= \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\hat{w}_n - \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\hat{w}_i - \sum_{k\in K}\theta_k\xi^k_{iR}\hat{\tau}^k_{iR} + \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\left[\sum_{l\in\mathcal{R}}\theta_k\pi^k_{ln}\hat{w}_l\right]\ldots \\
&+ \sum_{k\in K}\xi^k_{iR}\left[\sum_{l\neq R}\theta_k\pi^k_{lR}\hat{\tau}^k_{lR}\right] + \sum_{k\in K}\sum_{n\neq R}\xi^k_{in}\theta_k\pi^k_{Rn}\hat{\tau}_{Rn} + \sum_{k\in K}\xi^k_{iR}\theta_k\pi^k_{RR}\hat{\tau}^k_{RR} - \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\pi^k_{in}\hat{A}^k_R
\end{aligned}$$

Rearranging terms and imposing $\hat{\tau}^k_{iR} = \hat{\tau}_{HR}\ \forall\ i \in$ Home we get:

$$\begin{aligned}
\hat{w}_i &= \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\hat{w}_n - \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\hat{w}_i - \sum_{k\in K}\theta_k\xi^k_{iR}\hat{\tau}_{HR} + \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\left[\sum_{l\in\mathcal{R}}\pi^k_{ln}\hat{w}_l\right]\ldots \\
&+ \sum_{k\in K}\theta_k\xi^k_{iR}\left[\sum_{l\neq R}\pi^k_{lR}\right]\hat{\tau}_{HR} + \sum_{k\in K}\sum_{n\neq R}\theta_k\xi^k_{in}\pi^k_{Rn}\hat{\tau}_{RH} + \sum_{k\in K}\theta_k\xi^k_{iR}\pi^k_{RR}\hat{\tau}^k_{RR} - \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\pi^k_{Rn}\hat{A}^k_R
\end{aligned}$$

Rearranging all terms to put the direct effect first we have:

$$\begin{aligned}\Rightarrow\quad \hat{w}_i &= \sum_{k\in K}\sum_{n\neq R}\theta_k\xi^k_{in}\pi^k_{Rn}\hat{\tau}_{RH} - \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\pi^k_{Rn}\hat{A}^k_R + \sum_{k\in K}\theta_k\xi^k_{iR}\pi^k_{RR}\hat{\tau}^k_{RR}\dots\\ &\dots - \sum_{k\in K}\theta_k\xi^k_{iR}\left(1-\sum_{l\neq R}\pi^k_{lR}\right)\hat{\tau}_{HR} + \sum_{k\in K}\sum_{n\neq i}\xi^k_{in}\hat{w}_n + \sum_{k\in K}\xi^k_{ii}\hat{w}_i - \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\hat{w}_i\dots\\ &\dots + \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\left[\sum_{l\neq i}\pi^k_{ln}\hat{w}_l + \pi^k_{in}\hat{w}_i\right]\end{aligned}$$

$$\begin{aligned}\Rightarrow\quad \hat{w}_i &= \sum_{k\in K}\sum_{n\neq R}\theta_k\xi^k_{in}\pi^k_{Rn}\hat{\tau}_{RH} - \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\pi^k_{Rn}\hat{A}^k_R + \sum_{k\in K}\theta_k\xi^k_{iR}\pi^k_{RR}\hat{\tau}^k_{RR}\dots\\ &\dots - \sum_{k\in K}\theta_k\xi^k_{iR}\left(1-\sum_{l\neq R}\pi^k_{lR}\right)\hat{\tau}_{HR} + \sum_{k\in K}\xi^k_{ii}\hat{w}_i - \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\hat{w}_i + \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}\pi^k_{in}\hat{w}_i\dots\\ &\dots + \sum_{k\in K}\sum_{h\neq i}\xi^k_{ih}\hat{w}_h + \sum_{k\in K}\theta_k\sum_{n\in\mathcal{R}}\xi^k_{in}\left[\sum_{l\neq i}\pi^k_{ln}\hat{w}_l\right]\end{aligned}$$

Thus equilibrium wage changes in a region can be decomposed as follows:

$$\begin{aligned}\hat{w}_i &= \sum_{k\in K}\sum_{n\neq R}\theta_k\xi^k_{in}\pi^k_{Rn}\hat{\tau}_{RH} - \sum_{k\in K}\sum_{n\in\mathcal{R}}\xi^k_{in}\pi^k_{Rn}\hat{A}^k_R + \sum_{k\in K}\theta_k\xi^k_{iR}\pi^k_{RR}\hat{\tau}^k_{RR}\dots\\ &\dots - \sum_{k\in K}\theta_k\xi^k_{iR}\left(1-\sum_{l\neq R}\pi^k_{lR}\right)\hat{\tau}_{HR} + \underbrace{\sum_{k\in K}\xi^k_{ii}\hat{w}_i - \sum_{k\in K}\sum_{n\in\mathcal{R}}\theta_k\xi^k_{in}(1-\pi^k_{in})\hat{w}_i}_{\text{own region indirect effect}}\dots\\ &\dots + \underbrace{\sum_{k\in K}\sum_{h\neq i}\xi^k_{ih}\hat{w}_h + \sum_{k\in K}\sum_{h\neq i}\theta_k\left[\sum_{n\in\mathcal{R}}\xi^k_{in}\pi^k_{hn}\right]\hat{w}_h}_{\text{other region indirect effect}}\end{aligned} \tag{A.2}$$

B Data Appendix

B.1 Trade flows

B.1.1 Country-to-country trade data

Data on international (i.e. country-to-country) trade flows is obtained from the World Input-Output database (WIOD) (Timmer et al. (2015)). The advantage of this dataset is that it allows to obtain trade of each country with itself.

Table B1: List of Countries used in Counterfactual Exercises

No.	**Country Name**	**Country Code**
1	Australia	AUS
2	Austria	AUT
3	Brazil	BRA
4	Canada	CAN
5	China	CHN
6	Germany	DEU
7	Spain	ESP
8	Finland	FIN
9	France	FRA
10	United Kingdom	GBR
11	Greece	GRC
12	Hungary	HUN
13	Indonesia	IDN
14	India	IND
15	Ireland	IRL
16	Italy	ITA
17	Japan	JPN
18	South Korea	KOR
19	Mexico	MEX
20	Netherlands	NLD
21	Portugal	PRT
22	Sweden	SWE
23	Turkey	TUR
24	United States	USA
25	Rest of the World	ROW

B.1.2 State-to-country trade data

Data on trade flows between Brazilian states and foreign countries is obtained from Comex-Stat (MDIC (2018)).This dataset reports the f.o.b. value of exports and imports in current US dollars at the 8-digit Mercosur's Common Nomenclature (NCM96, Nomenclatura Comum do Mercosul).

B.1.3 State-to-state trade data

Trade flows between Brazilian states at the sector level are from Vasconcelos and Oliveira (2006). This data corresponds to the year 1999 and is reported using the 2-digit Brazilian National Classification of Economic Activities (CNAE), which has a total of 59 industry codes. The original data corresponds to exports by Brazilian states to other states. However, six states (Acre, Amapá, Ceará, Maranhão, Rio Grande do Norte, and Roraima) did not report exports. Since the other 21 states report exports to the 6 missing states, this allows us to recover import flows for all 27 states. We run PPML gravity regressions - i.e. trade flows on origin output, origin area, distance between origin and destination and destination fixed effects separately for each sector and dropping Amazonas. We then predict flows for each sector-origin-destination combination, and use these predicted flows for the 6 states for which flows we missing.

B.1.4 Trade with self

We use data on output from the Brazilian Institute of Geography and Statistics (IBGE) to calculate trade with self for each state as a residual. The first step is to calculate output for each of the 16 sectors an each state. We use IBGE's regional accounts to obtain the value of output at the state level for agriculture, mining, manufacturing, and services. This data presents manufacturing as an aggregate. Therefore, we complement this data with the IBGE's Annual Industrial Survey (Pesquisa Industrial Anual, PIA) of the year 1999 to obtain the value of output for the 13 manufacturing industries at the state level. We calculate for each state the share of each of the 13 industries in total manufacturing output, and we apply this share to the regional accounts data. In this way we can obtain output for the 13 manufacturing industries and the 3 other sectors (agriculture, mining, and services). All values are in current Reais and converted to US dollars using exchange rates from the World Development Indicators Database. Once we have output for each sector and state we substract exports to other states and exports to other countries to obtain exports to self. Since the data come from different sources, it is possible to obtain negative values. In addition, it is possible that output for a given state and manufacturing sector is missing or zero. We use the following imputation rules in these cases: (i) If output is zero and exports to other states and to the world are greater than zero, then we set output equal to total exports; (ii) If trade with self is negative but output is greater than zero, then we set exports to Brazilian states equal to: $X_{BRA}^{new} = \frac{X_{BRA}}{X_{BRA}+X_{WLD}} Output$.

B.2 Trade elasticities

We use sector specific trade elasticities from Caliendo and Parro (2015), using the sectoral aggregation in Costinot and Rodriguez-Clare (2014). Table B2 contains the final list of 16 sectors, and their corresponding elasticities.

Table B2: Industries and Trade Elasticities

No.	Industry Description	ISIC Rev. 3	Trade Elasticity
1.	Agriculture, hunting, forestry and fishing	1-5	8.11
2.	Mining and quarrying	10-14	15.72
3.	Food, beverages and tobacco	15-16	2.55
4.	Textile and textile products; Leather and footwear	17-19	5.56
5.	Wood and products of wood and cork	20	10.83
6.	Pulp, paper, printing and publishing	21-22	9.07
7.	Coke, refined petroleum and nuclear fuel	23	51.08
8.	Chemicals and chemical products	24	4.75
9.	Rubber and plastics	25	1.66
10.	Other non-metallic mineral	26	2.76
11.	Basic metals and fabricated metal	27-28	7.99
12.	Machinery, nec	29	1.52
13.	Electrical and optical equipment	30-33	10.60
14.	Transport equipment (Auto)	34-35	0.37
15.	Manufacturing nec; Recycling (Other)	36-37	5.00
16.	Services	40-95	5.00

B.3 Tariffs

Average ad-valorem tariffs applied by Brazil at the sectoral level for 1990 and 1998 are taken from Kume et al. (2000). Since we do not have reliable tariff data for 1999–the base year for counterfactual exercises–we assume tariffs in 1999 remained at the same level as in 1998. The authors start from data at the tariff-line level and aggregate it using simple averages up to SCN (Sistema de Contas Nacionais), the Brazilian National Accounts sector classification, at the 4-digit level (also called "Nivel 80" or Level 80). Then, they aggregate the data to the 2-digit level (also called SCN 43) using industry value added weights. We aggregate their data from SCN 43 to our industry classification using value added weights in 1990, obtained from IBGE. The tariff levels in 1990 and 1998 for each of the fifteen industries are given in the Table B3.

Table B3: Tariffs in 1990 and 1998

No.	Industry Description	Tariffs 1990	Tariffs 1998
1.	Agriculture, hunting, forestry and fishing	5.9	9.9
2.	Mining and quarrying	5.46	2.19
3.	Food, beverages and tobacco	33.04	16.07
4.	Textile and textile products; Leather and footwear	38.22	20.27
5.	Wood and products of wood and cork	25.4	14
6.	Pulp, paper, printing and publishing	23.6	14.2
7.	Coke, refined petroleum and nuclear fuel	19.4	5.4
8.	Chemicals and chemical products	25.22	13.81
9.	Rubber and plastics	41.60	17.04
10.	Other non-metallic mineral	31.50	13.6
11.	Basic metals and fabricated metal	25.00	14.73
12.	Machinery, nec	37.20	17.7
13.	Electrical and optical equipment	42.15	18.33
14.	Transport equipment (Auto)	51.50	25.19
15.	Manufacturing nec; Recycling (Other)	41.60	16.4

B.4 Industry crosswalks

The industrial classifications are not uniform across different data sources, so we use different crosswalks to arrive at a final classification of 15 tradable sectors (that include agriculture, mining, and 13 manufacturing sectors) and a non-tradable sector. Our final classification combines sectors at the 2-digit level of the ISIC Rev. 3 classification, which is the classification of the WIOD data. We follow the 16-sector aggregation of Costinot and Rodriguez-Clare (2014) (see B2), which is also based on WIOD and that allows to use the trade elasticities estimated by Caliendo and Parro (2015).

Brazilian imports and exports are expressed in the 8-digit Common Nomenclature of Mercosur (NCM) in its 1996 version. At the six-digit, this nomenclature is equivalent to HS 1996. We then use the mapping provided by UN to convert from 6-digit HS 1996 to ISIC Rev. 3. Aggregating from ISIC-3 to our 16-sector classification is straightforward.

Interstate trade and state's output are reported using the 2-digit CNAE classification, which is equivalent to 2-digit ISIC Rev.3, so the mapping to our final classification is straightforward.

Finally, tariffs are converted from SCN43 to CNAE using a mapping provided by IBGE.[7] The mapping has many-to-many matches at the 2-digit level, so we created our own one-to-one mapping, available upon request.

[7] See http://concla.ibge.gov.br/classificacoes/correspondencias/atividades-economicas

C Results Appendix

C.1 Gravity and inter-state trade

Table C1: Inter-state trade gravity estimation. PPML estimates.

Sector	Distance	s.e.	Origin GDP	s.e.	Dest. GDP	s.e.	Obs.	R-sq
Agriculture	-1.374***	0.217	0.429***	0.146	0.523***	0.136	520	0.160
Mining	-1.854***	0.377	0.592**	0.296	0.872***	0.267	520	0.216
Food	-0.947***	0.132	0.645***	0.056	0.768***	0.059	520	0.814
Textile	-0.699***	0.139	0.806***	0.072	0.742***	0.081	520	0.807
Wood	-0.844***	0.191	0.288***	0.087	0.876***	0.091	520	0.403
Paper	-1.129***	0.147	1.112***	0.093	0.766***	0.091	520	0.947
Petroleum	-0.965***	0.202	0.994***	0.118	0.755***	0.125	520	0.740
Chemicals	-0.629***	0.190	1.150***	0.111	0.800***	0.124	520	0.885
Plastic	-0.711***	0.136	1.150***	0.080	0.859***	0.078	520	0.957
Minerals	-1.203***	0.158	0.723***	0.081	0.655***	0.086	520	0.733
Metal	-0.623***	0.235	0.937***	0.113	0.956***	0.153	520	0.738
Machinery	-0.371**	0.181	1.266***	0.090	0.776***	0.094	520	0.906
Electrical	-0.374**	0.169	1.600***	0.093	1.087***	0.098	520	0.982
Auto	-0.131	0.143	1.503***	0.092	1.009***	0.126	520	0.854
Other	-0.774***	0.156	0.941***	0.068	0.786***	0.082	520	0.840

The estimates in each row correspond to a regression at the sectoral level where the dependent variable is exports from an origin state to a destination state in a sector. The regressors are the logarithm of: the geographic distance between the centroids of the states, the sectoral GDP of the origin state, and the sectoral GDP of the destination state. The number of observations is equal to 26×20, where 26 is the number of origin states (excluding Amazonas since it contains a free-trade zone) and 20 is the number of destination states, also excluding Amazonas and six other states for which there is no data on exports (see Data Appendix for more details).
Robust standard errors. (***) $p < 0.01$, (**) $p < 0.05$, (*) $p < 0.1$.

C.2 Intra-country dispersion in manufacturing import shares

Figure C1: Share of total imports in manufacturing expenditure

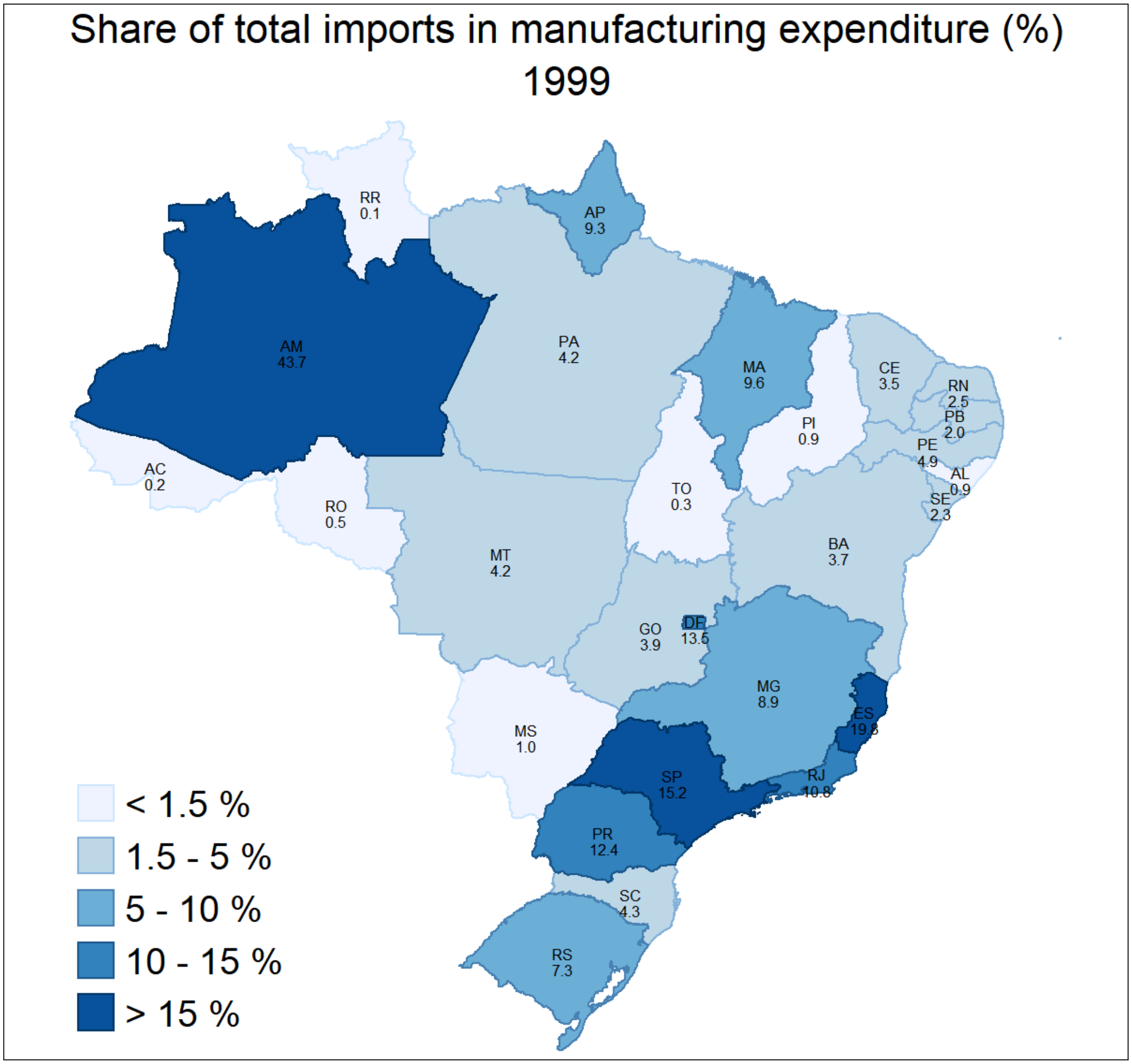


Figure C2: Share of USA in total manufacturing imports

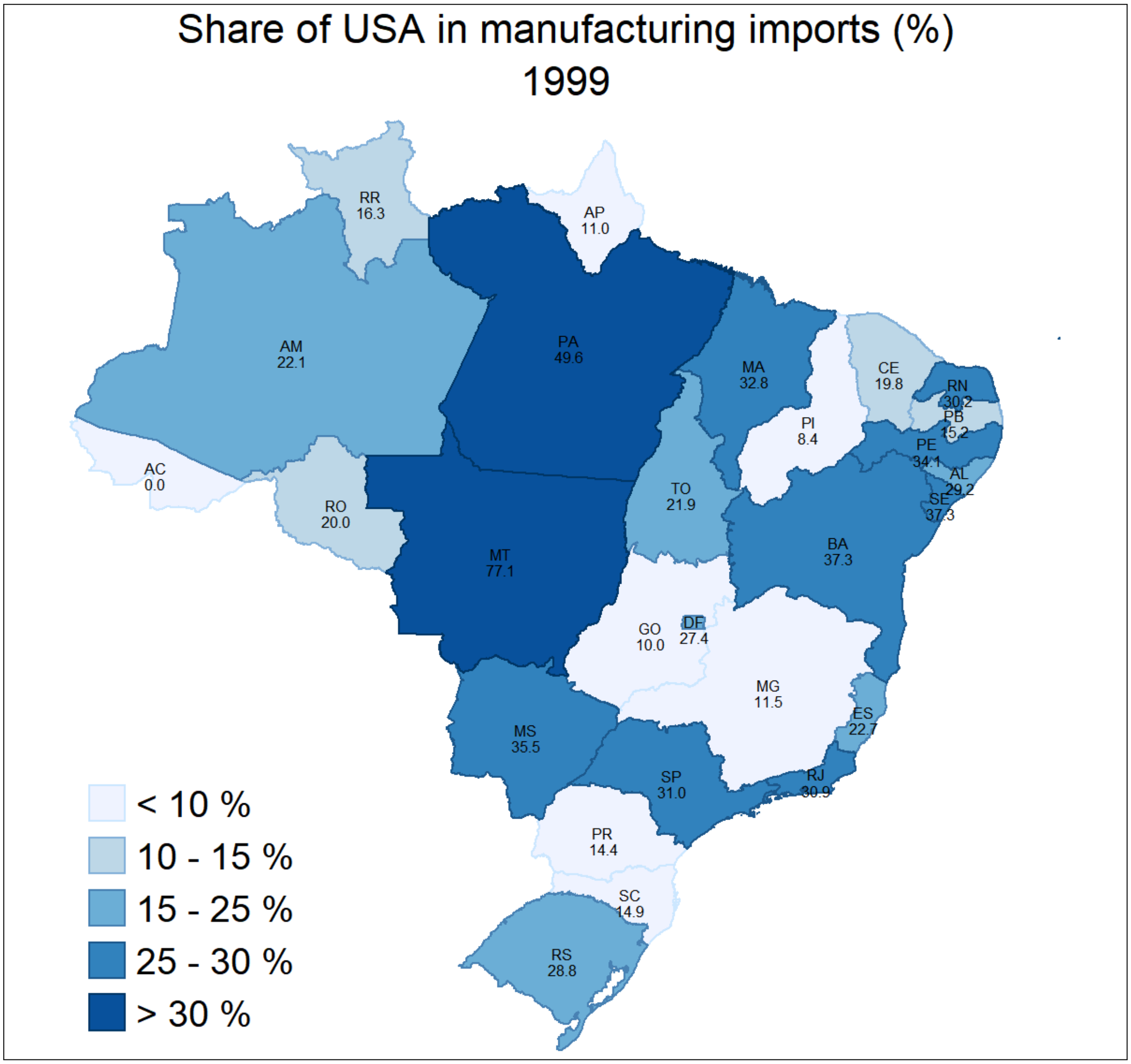


Figure C3: Share of China in total manufacturing imports

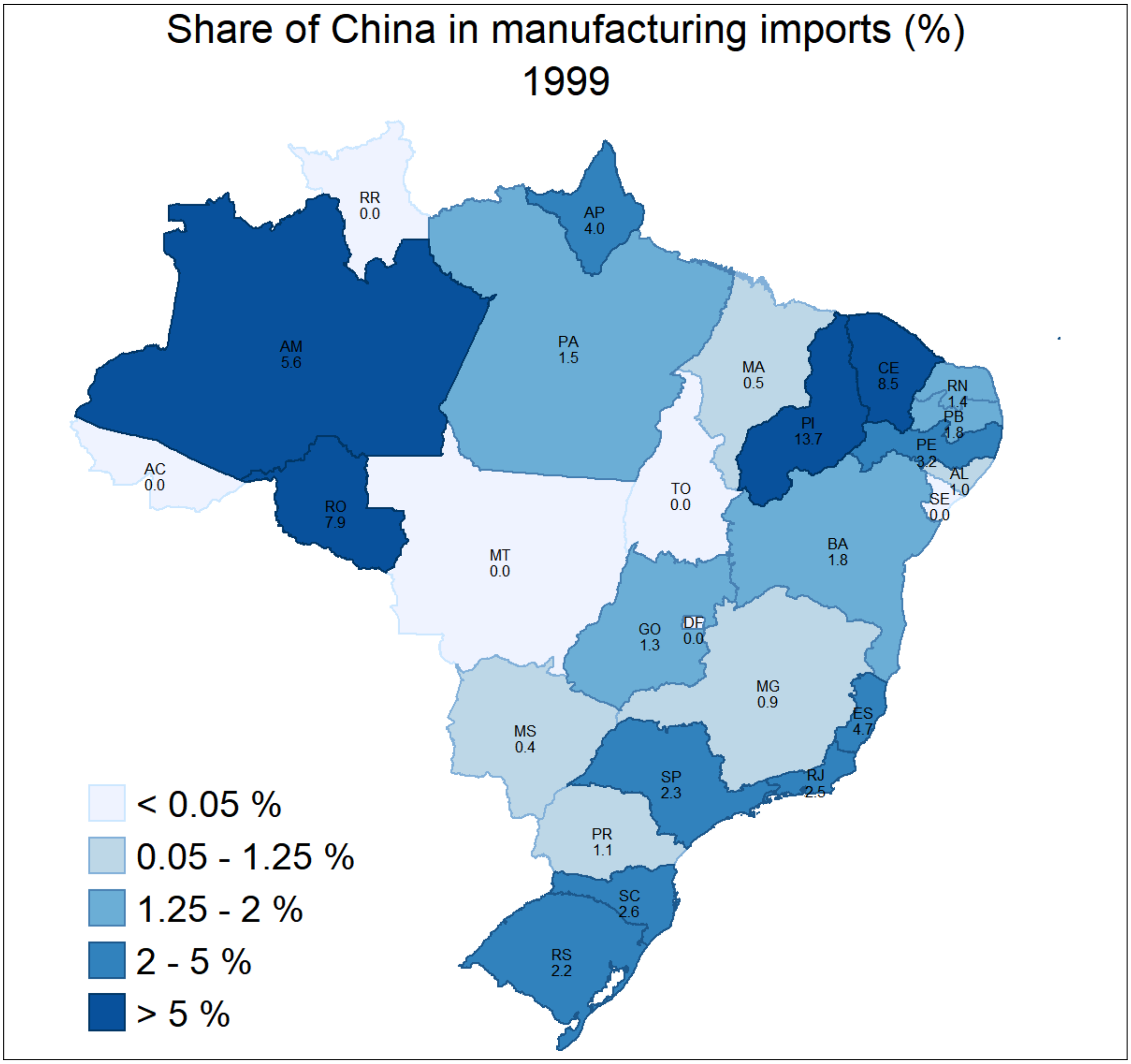
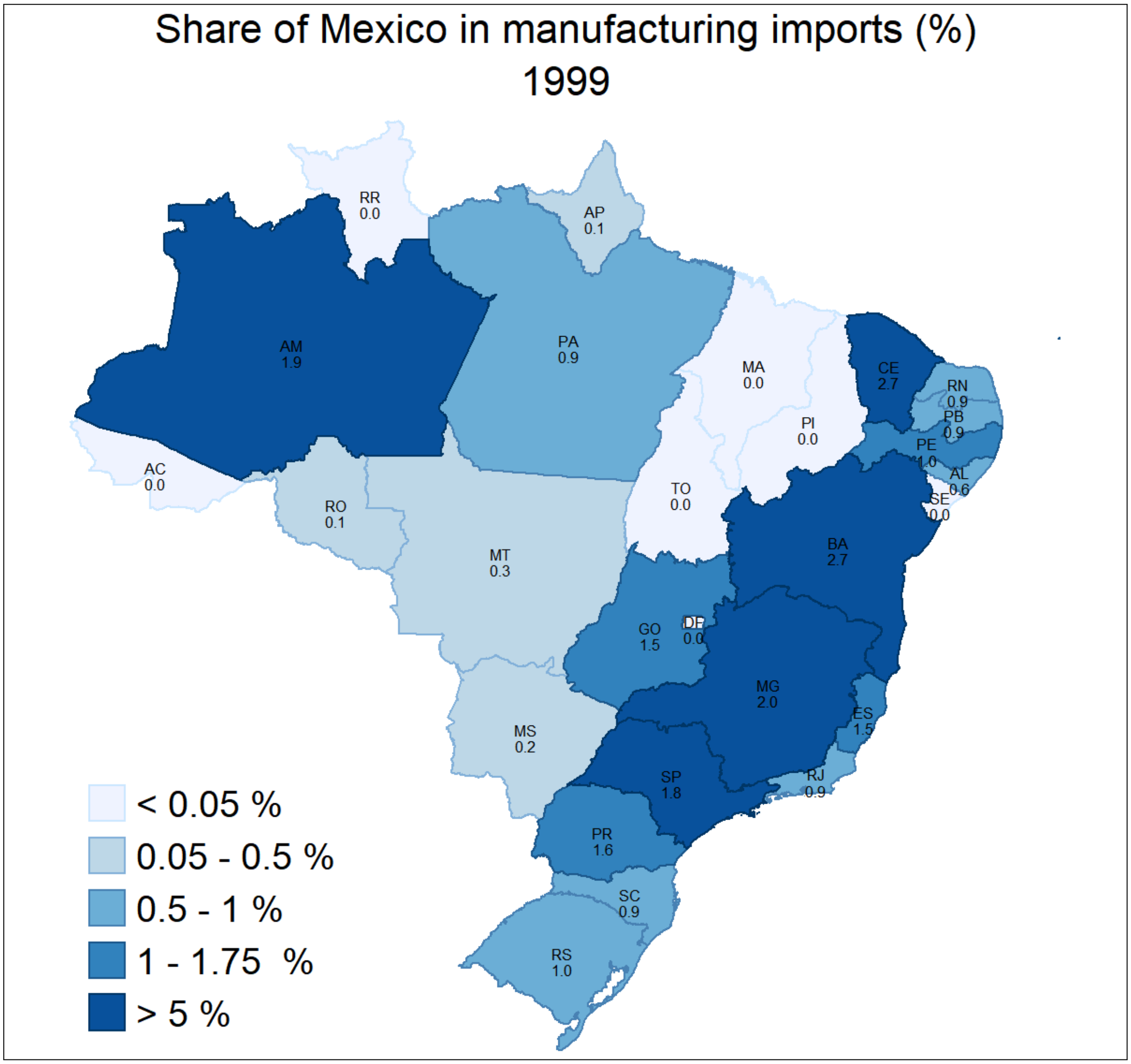


Figure C4: Share of Mexico in total manufacturing imports



C.3 Pearson Correlation of exposure measures by industry and source country

Figure C5: Pearson Correlation of *DE* and *ETC* exposure measures by industry and source country