Trade liberalization and inter-industry productivity spillovers: an analysis of the 1989-1998 Brazilian trade liberalization episode

Paz, Lourenco

Syracuse University

15 February 2012

Inter-industry Productivity Spillovers:

An Analysis Using the 1989–1998 Brazilian Trade Liberalization

March 27, 2013

Lourenço S. Paz*
lspaz@maxwell.syr.edu
110 Eggers Hall
Syracuse University
Syracuse, NY 13244 USA
Phone: 1 (315) 443-5874
Fax: 1 (315) 443-3717

Abstract

Since the 1980s, a common goal of the trade liberalization conducted by developing countries has been to increase manufacturing productivity. The literature has found evidence supporting such an increase in productivity; however, little is known about tariff-induced inter-industry (vertical) productivity spillovers. This paper proposes a new empirical methodology using spatial econometrics, and applies it to the large economy-wide shock represented by the Brazilian 1989–1998 trade liberalization. My results indicate the existence of positive and substantial upstream productivity spillovers. Nevertheless, no evidence of downstream productivity spillovers was found.

Keywords: import tariff; spatial econometrics; spillovers; trade liberalization

JEL Codes: F1, L6, C23

* I would like to thank Badi Baltagi, Chihwa Kao, Derek Laing, and Devashish Mitra for their helpful comments, Marc-Andreas Muendler for providing the Brazilian industry-level productivity series, Honório Kume for providing Brazilian import tariff data, and Wael Moussa for excellent research assistance. Thanks are also due to seminar participants at the Midwest International Trade Meeting. Any remaining errors are mine.

1. Introduction

Because productivity is a key factor for economic growth, the trade liberalization-productivity increase nexus in developing countries has received considerable scholarly attention. In a survey on this topic, López (2005) points out that several studies find that output tariff cuts increase industry-level productivity. Recently, the literature also found that input tariff cuts increase industry-level productivity in Indonesia (Amiti and Konings, 2007), India (Khandelwal and Topalova, 2011), and Brazil (Schor, 2004).

Another important branch of the literature has focused on inter- and intra-industry productivity spillovers, such as Henderson (2003) and López and Südekum (2009).[1] Interestingly, Henderson (2007) argues that a major problem faced by researchers interested in spillovers is the difficulty of finding large exogenous variations that are useful to identify spillovers. Given that trade liberalizations in developing countries are large economy-wide shocks, they can be used to identify such productivity spillovers.

In view of the remarks made above, I propose in this paper a new empirical methodology to estimate the magnitude of the inter-industry (or vertical) productivity spillovers. Next, I apply this new methodology to estimate the upstream and downstream inter-industry productivity spillovers using the Brazilian 1989–1998 trade liberalization. To the best of my knowledge, this is the first paper to investigate the existence of inter-industry productivity spillovers using spatial econometrics and also the first to use a trade liberalization episode as an economic shock. As will be discussed later, spatial econometric techniques are needed to address the simultaneous determination of industry-level productivities that arise in the presence of spillovers.[2]

To explore the effects of trade policy changes on productivity, I use data from the Brazilian 1989–1998 trade liberalization episode. The Brazilian experience offers a good benchmark because it has been studied extensively—see Muendler (2004a), Ferreira and Rossi (2003), and Schor (2004)—and the findings indicate that trade liberalization increased industry-level productivity. In particular, Muendler (2004a) estimated industry-level total factor productivity (TFP) using firm-level data, providing good quality industry-level TFP estimates that are used herein. Furthermore, since industry-level data are not protected by confidentiality, their use in this paper to illustrate the new methodology is ideal because the data used is available to other researchers not only to replicate my results but also to further scrutinize the role of productivity spillovers.[3]

The results of my analysis imply that inter-industry upstream spillovers are positive and can account for 60-80% of the increase in industry-level TFP due to trade liberalization. My preferred estimates indicate that a 10 percentage point decrease in tariffs across all industries increases TFP by 5.69%, 1.25% of which is the direct effect of tariffs while the remaining 4.44% is due to inter-industry upstream productivity spillovers. Lastly, I find no evidence of the existence of inter-industry downstream productivity spillovers.

The salience of upstream spillovers and the irrelevance of downstream spillovers are in line with the findings of López and Südekum (2009), which are closely related to this paper. López and Südekum (2009) investigate inter-industry spillovers that are due to agglomeration effects. In particular, they use Chilean manufacturing plant-level data and find that the larger the number of plants from upstream industries located in the same region, the higher the plant productivity. Additionally, they find that the number of plants from downstream industries located in the same region does not affect plant productivity. My paper differs from theirs by conducting the analysis at the industry level and defining the notion of industry proximity not by physical distance but instead according to the industry purchases of intermediate inputs from the other industries. This article also relates to the literature that examines the effect of tariffs on industry-level productivity, such as Schor (2004), Fernandes (2007), and Karacaovali (2011). My results confirm their findings that both output and intermediate input tariffs increase industry-level productivity.

The remainder of the paper is organized as follows. The next section discusses in more detail the weaknesses of the methodology that has been used in previous studies, and describes the methodological improvements introduced in this paper. The data set used in the empirical analysis is described in Section 3. Section 4 reports my estimates and discusses the results. Finally, conclusions are presented in Section 5.

2. Methodology

In this section, I briefly present the literature's current approach to infer the effects of trade liberalization on productivity. Next, I introduce a new methodology to estimate the magnitude of both upstream and downstream inter-industry productivity spillovers, and I discuss its implications.

2.1 Current Approach

Several developing countries—such as Brazil, Colombia, and India—decided in the 1980s and 90s to change their trade policies towards a freer trade environment. Such policy change consisted of import tariff cuts and the elimination of non-tariff barriers. As discussed in Muendler (2004a) and Karacaovali (2011), one important goal of this type of trade reform is to enhance productivity in the manufacturing sector.

There is a large body of literature concerned with the effects of trade policy changes on productivity. The measure of productivity commonly used in the literature is the TFP. The TFP is the change in the level of output that cannot be explained by changes in the quantity of factors of production, such as capital, intermediate inputs (materials), and labour. This residual is composed of random shocks, process innovations, managerial effort and reorganization, increases in workers' knowledge, and knowledge embodied in intermediate inputs – all of which are unobservable to the researcher. See Van Beren (2011) for a survey on the TFP estimation methods.

The trade policy changes commonly considered by researchers are decreases in the output good tariffs and intermediate input good tariffs. An output tariff cut can affect industry-level productivity through two channels. First, it increases competition in domestic markets and thus forces firms to reduce their x-inefficiencies through managerial restructuring (see Pavcnik, 2002; Krishna and Mitra, 1998). Second, industry-level productivity may also increase due to output reallocation from low-productivity firms to high-productivity firms, as shown in the Melitz (2003) model. Fernandes (2007), using Colombian firm-level data, finds evidence supporting the relevance of both channels.

Input tariffs can affect productivity for two reasons. First, Corden (1971) predicts that a decrease in input tariffs will decrease productivity because cheaper inputs will weaken competitive pressure in the output market; in other words, the effective rate of protection will increase. Second, the theoretical models in Ethier (1982), Markusen (1989), and Grossman and Helpman (1991) predict that lower input tariffs induce higher productivity through access to a larger variety and better quality of intermediate inputs as well as knowledge spillovers. These conflicting theoretical results suggest that the overall effect of the input tariff on TFP is an empirical question. The effect of the input tariff is estimated in Schor (2004) for Brazil, by Amiti and Konings (2007) for Indonesia, and by Khandelwal and Topalova (2011) for India. These three empirical studies find that a cut in input tariffs increases TFP.

The effects of both tariffs on TFP have been estimated in the literature by means of equation (1),

$$\Delta tfp_{it} = c + \gamma_1 * \Delta output\_tariff_{it} + \gamma_2 * \Delta input\_tariff_{it} + \boldsymbol{\beta}' \Delta \mathbf{x}_{it} + \theta_t + \Delta u_{it} \qquad (1)$$

where tfp_{it} is the natural logarithm of the estimated TFP for industry i at time t, $output\_tariff_{it}$ is the import tariff charged on the output produced by industry i at time t, $input\_tariff_{it}$ is the import tariff charged on the inputs used by industry i at time t, $\boldsymbol{x_{it}}$ is a vector of other time and industry-varying control variables, θ_t represents year fixed effects, u_{it} is the error term, and Δ is the time difference operator, for instance, $\Delta tfp_{it} \equiv tfp_{it} - tfp_{it-1}$.

Year effects are included in the specification to control for economy-wide shocks, that is, variables that increase or decrease together in different industries during the same business cycle. For instance, if firms are prone to conduct managerial reorganizations during a recession, but at the same time the government raises tariffs in response to the recession, a spurious relationship will be found between tariffs and productivity unless year effects are used.

Equation (1) is in first difference for two reasons. First, TFP levels are expressed in conceptual units that are not comparable across industries. Consequently, the identification must come from within-industry variation, which is achieved by estimating equation (1) with year effects and in first difference. Second, the possible existence of omitted industry-specific and time-invariant characteristics that are correlated with right-hand-side variables leads to inconsistent estimates; however, such omitted variables are cancelled out by the first difference. One example of such industry-specific characteristics is labour or environmental regulations that affect industries differently and may constrain adjustments in some factors of production.

2.2 New methodology to estimate productivity spillovers

The agglomeration literature—Henderson (2003), Rosenthal and Strange (2003), and López and Yadav (2010)—has suggested some possible mechanisms for inter-industry spillovers, which I use to motivate my investigation of the trade liberalization-productivity spillovers nexus. Trade liberalization may increase competition in the input market; it also improves firms' access not only to cheaper and better quality inputs but also to a larger variety of them (for instance, see Goldberg et al., 2010).[4] This increase in competition forces domestic input producers not only to increase their efficiency but also to upgrade the quality of their products and even to embody more knowledge in the inputs produced, for instance, by imitating the newly imported competing intermediate inputs. Such improvements will be reflected in the input producers' productivity, which will spill over to the industries purchasing those inputs. These linkages can be seen clearly in the Input-Output (I-O) matrix. This type of inter-industry (vertical) spillover is of an upstream nature (hereafter 'upstream spillover'). For the abovementioned reasons, I expect productivity spillovers to be positive.

Similarly, inter-industry spillovers may also be generated by downstream industries; that is, intermediate input producer productivity increases due to an increase in the productivity in the final good producer (hereafter 'downstream spillovers'). Such downstream spillovers could happen if a tariff cut increases competition in the final good markets, which in turn leads final good producers to demand better prices or quality from intermediate input suppliers. In some cases, final good producers may even provide blueprints and technical assistance to their suppliers in order to remain competitive. So, I also expect these spillovers to be positive.

The international trade literature has tried to control for such spillovers by adding a regressor that consists of aggregated TFP of upstream (or downstream) industries.[5] This upstream TFP variable, however, is an endogenous regressor since the upstream industry productivities are determined simultaneously with the downstream industry productivities because it is often the case that downstream industries also produce inputs used by upstream industries. Consequently, this approach does not provide consistent estimates.

To address this simultaneity problem, I use spatial econometrics techniques. Such techniques require the researcher to explicitly model how much one industry interacts with another by means of a weighting matrix **W**. Intuitively, the elements of **W** should be larger for industries that have larger interactions.

In the case studied here, the existence of interaction between industries can be seen clearly in the I-O matrix through the amount of inputs that one industry purchases from other industries. One way to measure this interaction is to use the share of inputs purchased by industry *i* from industry *j* (given by the I-O matrix) as the weights.[6] This would capture upstream spillovers. To capture downstream spillovers, the measure would be the share of output sold by industry *i* to industry *j*, also given by the I-O matrix.

Now, to build the weighting matrices, let the manufacturing sector have N industries. **W** is then a matrix of $N \times N$ dimensions, and without loss of generality, its rows are normalized to sum one, as is usually done in the spatial econometrics literature.[7] I also assume that **W**'s diagonal elements are zero to allow for identification of the estimated model. This assumption also implies that the within-industry spillovers are already included in the industry-level TFP measure. Let $\boldsymbol{tfp}_t$ be a vector of N×1 observations of the TFP (dependent variable) in year t. Then, the productivity spillovers are captured by the term $\boldsymbol{W \Delta tfp}_t$ (called the 'spatial lag') in equation (2),

$$\boldsymbol{\Delta tfp}_t = \delta \boldsymbol{W \Delta tfp}_t + \gamma_1 \boldsymbol{\Delta output\_tariff}_t + \gamma_2 \boldsymbol{\Delta input\_tariff}_t + \boldsymbol{\Delta x}_t \beta + \boldsymbol{\theta}_t + \boldsymbol{\Delta u}_t \quad (2)$$

where $\boldsymbol{\Delta u}_t$ is i.i.d. with zero mean and finite variance, and δ is expected to be positive.

By contrasting equations (1) and (2), we can see that the failure to account for inter-industry spillovers leads to inconsistent estimates of the effects of tariffs on the industry-level TFP. To illustrate this important point, let $\Delta\mathbf{X}_t$ be the matrix of all regressors, that is, $\Delta\mathbf{X}_t = (\Delta \boldsymbol{output\_tariff}_t, \Delta \boldsymbol{input\_tariff}_t, \Delta \boldsymbol{x}_t, \boldsymbol{\theta}_t)$. Suppose the econometrician omits the spillover term. Then, the new error term will be given by $\Delta\boldsymbol{\varepsilon}_t = \delta\boldsymbol{W}\Delta\boldsymbol{tfp}_t + \Delta\boldsymbol{u}_t$. Consistent estimates of the parameters require that $E[\Delta\boldsymbol{X}_t'\Delta\boldsymbol{\varepsilon}_t] = 0$. But the existence of spillovers prevents this condition from being met because $E[\Delta\boldsymbol{X}_t'\Delta\boldsymbol{\varepsilon}_t] = E[\Delta\boldsymbol{X}_t'\delta\boldsymbol{W}\Delta\boldsymbol{tfp}_t] + E[\Delta\boldsymbol{X}_t'\Delta\boldsymbol{u}_t] = E[\Delta\boldsymbol{X}_t'\delta\boldsymbol{W}\Delta\boldsymbol{tfp}_t] \neq 0$, since $\Delta\boldsymbol{tfp}_t$ is a function of $\Delta\boldsymbol{X}_t$. Accordingly, not accounting for the spillover term, the regressors become correlated with the error term, leading to inconsistent estimates.

Although equation (2) accounts for the existence of spillovers, there are a few aspects of it that merit further discussion. One important issue concerns the potential endogeneity of $\boldsymbol{W}$. For instance, suppose a firm in industry j has to decide whether to produce an intermediate input for its output good in-house or to outsource it. This generates simultaneity between TFP and the I-O matrix. Suppose further that under the current trade policy, this firm finds it more profitable to produce such input in-house. Now, a decrease in the tariffs of intermediate inputs makes the domestic input producer more productive, which in turn lowers its price. The firm in industry j re-evaluates its decision and opts to outsource the intermediate input. As a result, there is a change in the I-O matrix if this input ends up being produced by an industry $i \neq j$. The real weight of industry i increases while the weight for other industries decreases. The direction of the spillover coefficient bias can go either way depending on the relative increase of industry i TFP relative to other industries TFP gains.

Amiti and Konings (2007) and Schor (2004) assume that the firms' input mix is stable over time. In my case, after contrasting the Brazilian I-O tables for 1985, 1990, and 1995, I find that they are very similar. Consequently, the assumption that the input mix remains stable over time seems reasonable in my case. Thus, to prevent any contemporaneous correlation between TFP and the industries' input mix reported in the I-O matrix, I use the 1985 I-O matrix from five years before the start of the trade liberalization.

An additional problem is posed by the estimation of equation (2). The change in import tariffs induced by the trade liberalization may not be exogenous with respect to TFP, as pointed out by Karacaovali (2011). He developed a theoretical model in which industry TFP is an important political economy factor that affects tariff setting, reflecting the fact that the higher the current and expected future industry TFP, the greater the benefits of protection for firms in that industry, and thus the greater the incentives to lobby government for more protection. Consequently, ignoring this endogeneity issue leads to a downward bias in the effect of tariffs on productivity. Using data from Colombia's trade liberalization episode, Karacaovali (2011) finds empirical evidence that supports his theoretical model predictions. Hence, to obtain consistent estimates, it is necessary to use an excluded instrument for tariffs.

This reverse causality between TFP and tariffs has an important implication for the selection of instruments for import tariffs. Interestingly, Muendler (2004a) states that one of the key goals of the Brazilian trade liberalization was to improve productivity in lagging industries. This suggests that a lower pre-reform productivity level implies a larger tariff cut, which is why the literature generally uses the pre-reform tariff level as an instrument for changes in tariffs—see Ferreira and Rossi (2003); however, Karacaovali (2011) argues that the exclusion restriction for using the pre-reform tariff level as an instrument for tariff changes is not met, because the pre-reform tariff level takes into account the industry-level TFP present at that time, which in turn is correlated with the current TFP level.[8] This means that the instrument (pre-reform tariff level) and the error term are correlated.

To address this problem, I use Colombia's import tariffs during its trade liberalization episode (1984 to the mid-1990s) as an instrument for Brazil's import tariff.[9] Prior to their trade liberalization episodes, both the Colombian and Brazilian governments believed that their import substitution industrialization policies (which implied high levels of trade protection) were welfare-enhancing, in addition to the fact that import substitution was viewed as an institution or even an historical legacy that could not be changed due to political concerns.[10] At a certain point, however, governments realize that the gains from import substitution may be smaller than expected, and change their development policies by decreasing trade protection across all industries.[11] This ideological similarity in the trade policies adopted by both countries led to a tariff move in the same direction (downward) as a result of this change to a trade liberalization policy, implying a positive correlation between Brazilian and Colombian tariffs.

I believe that using Colombia's import tariffs as an instrument for Brazil's import tariffs is valid because Colombian tariffs are not affected by future Brazilian tariffs, since trade between these two countries is very small relative to their trade with other partners.[12] As a result, the possible effect of Colombia's productivity on its tariffs appears to be uncorrelated with the possible effect of Brazil's productivity on its tariffs. So, the exclusion restriction is met.

Given that $\boldsymbol{W\Delta tfp_t}$ is an endogenous regressor, I use a generalized method of moments estimator developed by Kelejian and Prucha (1999) called the 'Generalized Spatial Instrumental Variable' (GSIV) estimator. Let $\boldsymbol{h}_{it}$ be a vector of exogenous regressors (included instruments) and excluded instruments (based on Colombian tariffs). I also follow the suggestion in Kelejian and Prucha (1998) to use $\boldsymbol{Wh}_{it}$ and $\boldsymbol{W}^2\boldsymbol{h}_{it}$ as instruments for $\boldsymbol{W\Delta tfp_t}$. The advantage of using this GMM-type estimator is that it imposes a significantly smaller computational burden and prevents serious numerical problems when finding the eigenvalues of the weights matrix, which is required in the maximum likelihood estimator, see Kelejian and Prucha (1997).

As a robustness check, I assume that Δu_{it} presents a spatial correlation of the following form: $(1\text{-}\rho\boldsymbol{W})^{-1}\Delta\boldsymbol{u}_{it} = \Delta\boldsymbol{e}_{it}$, where $\boldsymbol{e}$ is a vector of i.i.d. error term with zero mean and finite variance. I account for such correlation by following the approach developed in Kelejian and Prucha (2007) and Kelejian and Prucha (2010).

A potential caveat of industry-level analysis conducted here is that, as highlighted in Fernandes (2007), the use of a specification like equation (1) at the industry level tends to underestimate the effects of tariffs on TFP. Furthermore, an additional criticism of the empirical strategy proposed here is that the productivity spillovers should be accounted for in the TFP estimation procedure; however, this idea poses two major problems. The first problem is related to data availability, since the researcher needs to know not only the inputs used by the firms but also which firm produced those inputs in order to coherently identify the productivity spillovers. To the best of my knowledge, such a comprehensive firm-level dataset does not exist. The second problem is the lack of available econometric techniques that—for instance, in an Olley and Pakes (1996) framework—produce consistent estimates when firm-level TFP is simultaneously determined across firms.

3. Policy Background and Data Description

In this section, I explain how the Brazilian trade policy changed in the 1989–1998 period, and discuss the sources of the Brazilian and Colombian import tariff data and their level of aggregation. This is followed by a detailed description of the TFP data. Finally, I describe the I-O table and the weighting matrices (*W*) used in the estimates.

3.1 The 1989–1998 Brazilian Trade Liberalization

Until the end of the 1980s, Brazil's trade policy was dictated by an import substitution development policy and the country's balance of payments deficits. The former implied different levels and types of protection across industries – in particular, high tariffs and non-tariff barriers (NTBs) on imported goods that competed with similar domestic products.[13] The latter resulted in increased tariffs across all industries to curb imports and generate trade balance surpluses. Moreover, Brazil used its developing country status under article XVIII of the General Agreement on Tariffs and Trade (GATT) to avoid participating in all tariff reduction rounds.

This trade policy started to change in 1988 when Brazil unilaterally decided to decrease the level of redundant protection. Tariffs were reduced to a level that would still curb imports, but, as stressed by Kume et al. (2003), no NTBs were eliminated. In 1990, Brazil's new president drastically reduced NTBs and adopted nominal tariff reductions scheduled to start in 1990 and end in 1994. Most important, the actual decrease in tariffs was not identical across industries. Moreover, the tariff reductions did not follow the planned schedule. Nonetheless, the tariff reductions had real effects on the economy, as imports of manufactured goods increased by more than 200% and import penetration increased from 5.7% to 11.6% between 1990 and 1998. Thus, the period I consider in my first difference specifications spans from 1988 until 1998.

3.2 Tariff Data

The 1988–1998 Brazilian import tariff data set is from Kume et al. (2003) and was originally aggregated from individual product tariff lines to IBGE's Nível 50 industry classification using industry value added as weights. The Colombian import tariff data at the 4-digit ISIC Revision-2 level for the 1982–1993 period comes from the Colombian National Planning Department. Notice that the 4-digit ISIC Revision 2 classification is not directly compatible with Nível 50 classification.[14] Hence, I had to further aggregate the tariff data to a 16-industry classification in which such compatibility exists.

3.3 TFP Data

The industry-level TFP series are from Muendler (2004a), who used firm-level data from the Pesquisa Industrial Annual, an annual survey conducted by the Instituto Brasileiro de Geografia e Estatística (IBGE) that consists of an unbalanced panel of roughly 9,500 medium- and large-sized firms.[15] Muendler (2004a) estimated the TFP for the 1986–1998 period using two methods.[16] The first TFP measure (OLS-TFP) was the estimated OLS residual of a Cobb-Douglas type production function.[17] The second TFP measure (OP-TFP) was estimated using an extended version of the Olley and Pakes (1996) methodology that takes into account endogenous firm entry and exit.

Muendler (2004a) aggregated the firm-level TFP data at IBGE's Nível 50 industry classification (27 manufacturing industries). To match the tariff data aggregation, I further aggregated the data to my 16-manufacturing-industry classification using industry value added as weights. The two measures are calculated using the unbalanced panel sample of all firms (All) and the balanced panel sample containing only those firms that stayed in the market (that is, those that had positive output) throughout the entire trade liberalization period (Stayers). Even though the coefficients of the production inputs vary across different measures, the TFP estimates exhibit very similar behaviour, as indicated by the high correlation among the measures (Table 1) and the descriptive statistics (Table 2).

3.4 The I-O Table and the Weighting Matrices

I use the 1985 I-O table for Brazil from IBGE (2006) to calculate the weighting matrices and the input tariff. The non-manufacturing sectors and all final use consumption columns are excluded. The original table used Nível 80 industry classification (48 manufacturing industries); however, I further aggregated it to 16 manufacturing industries in order to match the industry aggregation level dictated by the tariff data. This procedure leads to a 16×16 I-O matrix (Γ).

Following Schor (2004) and Amiti and Konings (2007), I construct the input tariff as the weighted average of output tariffs computed using equation (3),

$$input\_tariff_{it} \equiv \sum_j \omega_{ji} * output\_tariff_{jt} \quad (3)$$

where the weight (ω_{ji}) is the share of input produced by industry j used by industry i, as the entries of the I-O matrix. Similarly, the instrument for the Brazilian input tariffs is also calculated using equation (3) and Brazilian I-O matrix, but now the output tariffs are those from Colombia.

Lastly, the upstream and downstream weighting matrices (**W**) have zeroes in their main diagonal. For upstream spillovers, the other entries (w_{ij}) are the share of inputs purchased from industry j by industry i, as displayed by equation (4). For downstream spillovers, w_{ij} is the share of output sold by industry i to industry j.

$$w_{ij} = \frac{\Gamma(i,j)}{\sum_{k=1}^{16} \Gamma(k,j)}, with\ i \neq j\ and\ i, j = 1, \ldots, 16 \quad (4)$$

4. Empirical Results

In this section, I first follow the current approach in the literature and present estimates of equation (1) to assess the effects of output and input tariffs on industry-level productivity. All of these results are estimated using both TFP measures and the unbalanced panel sample (All). Next, I estimate the inter-industry upstream and downstream productivity spillovers. Ultimately, I find that upstream spillovers do exist and are positive, whereas no evidence of downstream spillovers is found. The section concludes with some robustness checks that support these results, including a falsification-type test.

4.1 Estimates Using the Current Approach

Estimates of equation (1) using the IV estimator are reported in Table 3. The estimated output tariff coefficients are always negative, and are statistically significant at the 5% level only if the input tariff is not included in the specification, like in columns (1) and (4). The input tariff coefficients are never statistically significant, and are positive if output tariff is also a regressor, like in columns (3) and (6), and negative whenever output tariff is not included. Additionally, the standard errors of both tariff coefficients increase significantly when they are included in the same specification. These sign switches and enlarged standard errors are symptoms of a collinearity problem in columns (3) and (6) specifications, which is likely to happen due to the high aggregation level of the data. Thus, I conducted a test in which the null hypothesis is that both output and input tariff coefficients are zero, and this null hypothesis is rejected at the 5% level in both columns (3) and (6).

In the first stage regression for columns (1), (2), (4), and (5), the coefficients of the excluded instruments based upon the Colombian tariff are positive and statistically significant at the 5% level, as expected. The Kleibergen-Paap weak identification Wald F-statistics for these specifications are larger than the Stock-Yogo reference values, so the excluded instruments are not weak here. For columns (3) and (6), the Kleibergen-Paap F-statistics are below 3, which are much smaller than Stock-Yogo critical values. This seems to be a consequence of the collinearity between input and output tariff, as discussed earlier. The null hypothesis of the exogeneity of output tariffs is rejected only at the 10% level for columns (1) and (3), which use OLS-TFP series; the *p*-values for OP-TFP specifications, columns (4), (5), and (6), are between 14.1% and 44%. Thus, the above estimates provide some support to my claim that tariffs are endogenous regressors in this type of specification, as also claimed by Karacaovali (2011).

4.2 Estimating Productivity Spillovers

The aggregation level of my dataset prevents the simultaneous estimation of upstream and downstream spillovers due to a collinearity problem between the respective spatial lags. Hence, I estimate them separately, as in López and Südekum (2009). Let's first estimate the inter-industry upstream productivity spillovers by estimating equation (2) with the GSIV estimator. The estimated coefficients are presented in Table 4. The output tariff coefficient is negative in all specifications. In columns (1), (3), (4), and (6), it is also statistically significant at the 5% level, and these are the specifications that do not include input tariffs. The input tariff coefficients are negative and not statistically significant in columns (2) and (5); however, when output tariff is also a regressor, the estimated input tariff coefficient becomes positive, as reported in columns (3) and (6), and is not statistically significant either. The null hypothesis that both output and input tariffs are zero is rejected at the 5% level for both columns (3) and (6). This pattern is similar to that reported in Table 3.

The upstream spillovers are captured by the coefficient of the TFP spatial lag ($\boldsymbol{W\Delta tfp_t}$) that is positive, between 0.597 and 0.814, and statistically significant at the 5% level in all specifications. Let's interpret this coefficient by focusing on column (4) estimates of 0.125 for output tariff and 0.780 for the spatial lag. The direct effect of output tariff implies that a 10 percentage point decrease in output tariff across all industries increases TFP in all industries by 1.25%. To calculate the magnitude of the inter-industry spillover effect, we first need to calculate the spatial multiplier defined in Anselin (2003), which is calculated as $(1-0.780)^{-1} - 1 = 3.55$. Then, the spillover effect is given by the product between the spatial multiplier and the output tariff coefficient: $3.55 \times 0.125 = 0.444$. This means that the productivity spillovers induced by a 10 percentage point decrease in output tariffs is a 4.44% increase in TFP. Thus, the total effect (that is, the sum of the direct and the spillover effects) is a 5.69% increase in TFP. When TFP spillovers are ignored, see column (4) of Table 3, the direct (and also total) effect of a 10% decrease in tariffs increases TFP by 1.48%. So, the omission of TFP spillovers implies a 20% upward bias of the direct effect of tariffs and a 75% downward bias of the estimated total effect.

In columns (3) and (6) of Table 4, the error term is allowed to have a spatial correlation structure given by the weighting matrix. The spatial correlation coefficients are negative and not statistically significant. I also estimated the specifications of columns (3) and (6) without the spatial correlation in the error term, and the results are similar and available upon request. Whenever the generalized method of moments is employed, weak identification is an important concern. Nevertheless, as pointed out by Pinkse and Slade (2010, p. 110), there is no work on this subject for spatial estimators.

Next, I re-estimate the specifications in Table 4 using a heteroskedastic robust estimator for the coefficients' standard errors, as developed in Kelejian and Prucha (2007, 2010). The results of this exercise are reported in Table 5. The estimates are very similar to those in Table 4 for the specifications without spatial correlation in the error term reported in columns (1), (2), (4) and (5). Now, in columns (3) and (6), the output tariff coefficient is negative and statistically significant in the specification that also includes input tariffs. Also, the input tariff coefficient is not statistically significant. It is positive for OLS-TFP and negative for OP-TFP. A joint test of the null hypothesis that both the output and input tariff coefficients are zero is rejected at the 5% level. The specifications that account for spatial correlation in the error term, columns (3) and (6), exhibit similar coefficients for the spatial lag of TFP, and the error spatial correlation coefficient is again negative, but it is now statistically significant at the 5% level. The key result from Table 5 is that the spatial lag of TFP remains positive and statistically significant, as shown in Table 4.

Now, let us turn to the downstream productivity spillover specifications based upon equation (2) and the downstream weighting matrix. The results are reported in Table 6. As before, the output tariff coefficient is negative, but it is statistically significant only when the input tariff is not included in the specification. Also, the input tariff this time is always negative and only statistically significant when output tariff is not included in the regression. The magnitude of the coefficients of both direct tariff effects is similar to those in Table 4.

The spatial lag of the TFP captures the downstream productivity spillovers. Its coefficient is always positive in Table 6, but it is never statistically significant, except in column (6). Notice that in this case, the error term spatial correlation coefficient is outside the (-1,1) interval; thus, column (6) estimates are invalid. I also estimated Table 6 specifications allowing for heteroskedastic error terms and obtained qualitatively similar results, which are available upon request. In sum, there is no evidence supporting the existence of downstream productivity spillovers.

4.3 Robustness Checks

I conducted four robustness checks of the empirical results presented earlier. The first, which concerns two issues raised by Schor (2004) and Amiti and Konings (2007), is the well-known problem of distinguishing between physical productivity and mark-ups in imperfectly competitive industries. The second is that the effect of tariff changes on TFP depends on the initial level of competitiveness present in the industry. This relies upon the assumption that the less competitive the industry initially is, the larger the x-inefficiencies are, and therefore the larger the possible TFP gain induced by trade liberalization. To address these two issues, Schor (2004) and Amiti and Konings (2007) added a measure of industry competitiveness (the Herfindahl index) to equation (1); however, this approach has a serious drawback because, in a Melitz (2003) theoretical framework, industry-level productivity and market concentration are simultaneously determined. This means that a time- and industry-varying Herfindahl index would be an endogenous regressor, a point that has been overlooked in the literature.[18]

Unfortunately, for Brazil, neither a good instrument for industry concentration nor the firm-level information that is needed to compute the Herfindahl index for each industry-year pair is available; however, Schor (2004) reports the Herfindahl index for each industry in 1986; that is, three years before the trade liberalization. This allows me to address the issue of initial industry competitiveness by creating a dummy variable (hereafter 'Herfindahl dummy') to distinguish industries with an initial low level of competitiveness from the others. The Herfindahl dummy is “1” for six industries (the top third) with the highest Herfindahl index (that is, industries with highly concentrated markets) and “0” otherwise. Then, I re-estimated Table 5 specifications adding an interaction between the Herfindahl dummy and the output tariff, and the coefficient of this term is expected to be negative. These new estimates are reported in Table 7.

The TFP spatial lag coefficient is positive and statistically significant at the 5% level in all Table 7 specifications. The magnitude of the output tariff decreased with respect to Table 5 results, and its standard deviation increased. Now, all the input tariff coefficients are negative, which is in line with the literature findings but not statistically significant in any of the specifications. Interestingly, the interaction between the Herfindahl dummy and the output tariff is negative as expected but not statistically significant. Unfortunately, the number of observations is too small to estimate the coefficients precisely, so I tested the null hypothesis of all three coefficients being equal to zero, and it was rejected at the 5% level for columns (1)-(3), which use OLS-TFP, and at the 10% level for columns (4)-(6), which use OP-TFP. A similar exercise was performed for the downstream spillover specifications. The TFP spatial lag coefficient was positive but not statistically significant, as shown in Table 6 results.

Table 7 results are important because they confirm that upstream productivity spillovers are present and positive. Second, the relative effect of input tariffs vis-à-vis output tariffs on TFP depends on the output market structure. For output markets with small concentration, the input tariff effect is similar to that of the output tariff for OLS-TFP and about two to four times larger for OP-TFP. For highly concentrated output markets, the effect of input tariffs is between 33% and 50% of the effect of the output tariff for both TFP series.

In the second robustness check, I conduct a falsification-type (placebo) test. This test consists of replacing the original upstream weighting matrix based on the I-O table by a randomly generated weighting matrix, which had the diagonal set to zero and each row normalized to sum to one. Then, I re-estimated the specifications from Table 5. These new estimates results are presented in Table 8.

Notice that if TFP upstream spillovers matter and happen through the I-O linkages, the estimated coefficient of the spatial lag should not be statistically significant, but the direct effect of output tariffs and input tariffs can still be statistically significant. We can see that in all Table 8 specifications (columns (1)-(6)), the spatial lag coefficient is not statistically significant. Furthermore, in columns (2), (3), (5), and (6) specifications, the spatial correlation in the error term is accounted for, and the estimated TFP spillover coefficient in these specifications is never statistically significant either. Thus, Table 8 results support my hypothesis that inter-industry upstream productivity spillovers exist and happen through the I-O linkages.

In the third robustness check, I estimated all the previous regressions using the TFP measures obtained by considering the balanced panel sample; that is, only those firms that remained in the sample throughout the trade liberalization period (Stayers). The results are very similar, and are available upon request. Finally, the fourth robustness check consists of re-estimating the previous specifications using TFP measures that were aggregated to my 16-industry classification using simple averages. Once again, the results are very similar and available upon request.

5. Conclusions

Productivity increase is a major driving force of economic growth. Several developing countries have used trade liberalization to boost productivity. In many cases, the empirical findings in the literature indicate that reductions in both output and input tariffs caused an increase in industry-level productivity—see Schor (2004), Amiti and Konings (2007), Fernandes (2007), and Karacaovali (2011). Nevertheless, none of these previous studies investigated the existence and the magnitude of inter-industry productivity spillovers in the context of a trade liberalization episode. This is unfortunate because trade liberalization constitutes a large economic shock and then provides a novel identification strategy, since the extant literature has examined productivity spillovers primarily by looking at agglomeration effects, see López and Südekum (2009). To fill this important gap in the literature, I propose a new methodology to estimate inter-industry (vertical) productivity spillovers using spatial econometric techniques, and apply it to the Brazilian 1989–1998 trade liberalization episode.

My findings indicate that inter-industry upstream spillovers not only exist but also have a positive effect on industry-level productivity. My preferred estimates indicate that these spillovers can account for 78% of the increase in industry-level TFP due to trade liberalization. When the upstream spillovers are ignored, the estimates of the direct impact of trade liberalization on productivity are biased upward by 20%, whereas the total effects are downward-biased by 75%. Finally, no evidence of downstream productivity spillovers is found. Interestingly, my results are in line with the agglomeration effect literature findings, like in López and Südekum (2009). An important avenue for future research is to identify the microeconomic mechanisms behind the productivity spillovers.

Notes

[1] The issue of productivity spillovers has been raised previously in the foreign direct investment literature, see, for instance, Javorcik (2004).
[2] Several papers have used spatial econometric techniques to cope with economic interdependence in international trade-related questions, for instance, Davies (2005), Blonigen et al. (2007), and Baltagi et al. (2008) study third-country effects of foreign direct investment.
[3] A weakness of such data, however, is that I will be unable to decompose the tariff effect into within-firm and between-firm effects to deepen the understanding of the productivity spillover mechanism. This is left for future research.
[4] Keller (2009) provides a very good literature review on this topic and discusses evidence that supports the argument that imports are an important channel of technology diffusion.
[5] For instance, Javorcik (2004) uses this approach, but the dependent variable is firm output level.
[6] The I-O matrix has been used in this way previously by Moreno et al. (2004) among others.
[7] This guarantees that the spatial lag coefficient (δ) will belong to the (-1,1), and allows it to be interpreted as the spatial multiplier as in Anselin (2003).
[8] Muendler (2004a) also found that industry-level TFP in Brazil has some time persistence.
[9] I match the year preceding the trade liberalization in Colombia (1984) to the year preceding trade reform in Brazil (1989). Hence, the 1984 Colombian tariff level is used as an instrument for the 1989 Brazilian import tariff, and so on.
[10] Karacaovali (2011) develops a similar argument in a theoretical model of the political economy of protection.
[11] For example, governments that adopted import substitution development policies may have observed that countries with trade-oriented development policies, like South Korea, have experienced higher levels of economic growth.
[12] According to Goldberg and Pavcnik (2005), in the early 1980s, the Colombian government negotiated with the World Trade Organization (WTO) to set tariffs to achieve a uniform tariff of 13% across industries.
[13] Kume et al. (2003) provide a comprehensive description of Brazil's trade policy in the 1980s and 1990s.
[14] One example of the incompatibility between 4-digit ISIC and Nível 50 is the ISIC code 3825 (Manufacture of office, computing and accounting machinery), which could be classified as Nível 50 codes 10 (electric equipment) or 11 (electronic equipment). A table containing the industry concordance of my 16-industry classification, 4-digit ISIC Rev. 2, and Nível 50 is available upon request.
[15] The survey was not conducted in 1991 due to budget cuts. To avoid losing a lot of observations due to first differencing of the data, I used linear interpolation to build the TFP observations for 1991, since all the other variables are available for that year. More details about the survey and its variables can be found in Muendler (2003).
[16] Interested readers can refer to Van Beveren (2011) for a survey on TFP estimation.
[17] A brief description of these strategies is presented in the appendix. A detailed explanation of the estimation procedures and their theoretical derivation can be found in Muendler (2004b).
[18] Moreover, as pointed out by Karacaovali (2011), industry concentration is an important factor in determining tariffs. So, it is not clear that the inclusion of a concentration measure will capture the desired effect.

References

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

Anselin, L. (2003). Spatial Externalities, Spatial Multipliers, and Spatial Econometrics. International Regional Science Review, 26 issue 2, 153-166.

Autant-Bernard, C. and J. P. LeSage (2011). Quantifying knowledge spillovers using spatial econometric models. Journal of Regional Science, 51, 471-496.

Baltagi, B., Egger, P., and M. Pfaffermayr (2008). Estimating Regional Trade Agreement Effects on FDI in an Interdependent World. Journal of Econometrics, 145, 194-208.

Blonigen, B., Davies, R., Waddell, G., and H. Naughton. (2007). FDI in space: Spatial autoregressive relationships in foreign direct investment. European Economic Review, 51(5), 1303-1325.

Corden, M. W. (1971). The Theory of Protection. Oxford: Oxford University Press.

Davies, R. (2005). State tax competition for foreign direct investment: a winnable war? Journal of International Economics, 67 (2), 498-512.

Ethier, W. (1982). National and International Returns to Scale in the Modern Theory of International Trade. American Economic Review, 72(3), 389-405.

Fernandes, A. M., (2007). Trade Policy, Trade Volumes and Plant-Level Productivity in Colombian Manufacturing Industries. Journal of International Economics 71, 52-71.

Ferreira, P. C. and J. L. Rossi (2003). New Evidence from Brazil on Trade Liberalization and Productivity Growth. International Economic Review, 44(4), 1383-1405.

Goldberg, P. and N. Pavcnik (2005). Trade, Wages, and the Political Economy of Trade Protection: Evidence from the Colombian Trade Reforms. Journal of International Economics, 66(1), 75-105.

Goldberg, P., A. Khandelwal, N. Pavcnik and P. Topalova. (2010). Imported Intermediate Inputs and Domestic Product Growth: Evidence from India. Quarterly Journal of Economics, 125(4), 1727-67.

Grossman, G. and E. Helpman. (1991). Innovation and Growth in the Global Economy. Cambridge, MA: MIT Press.

Henderson, J. V. (2003). Marshall's Scale Economies. Journal of Urban Economics, 53, 1-28.

Henderson, J. V. (2007). Understanding knowledge spillovers. Regional Science and Urban Economics, 37, 497-508.

IBGE (2006). Notas Técnicas Matriz de Insumo-Produto Brasil – 1985. Instituto Brasileiro de Geografia e Estatística.

Javorcik, B. S., (2004). Does Foreign Direct Investment increase the Productivity of Domestic Firms? In Search of Spillovers through Backward Linkages. American Economic Review, 94(3), 605-27.

Karacaovali, B., (2011). Productivity Matters for Trade Policy: Theory and Evidence. International Economic Review, 52(1), 33-62.

Kelejian, H. and I. Prucha (1997). Estimation of the Spatial Autoregressive Parameter by Two Stage Least Squares Procedures: A Serious Problem. International Regional Science Review, 20, 103-111.

Kelejian, H. and I. Prucha (1998). A generalized spatial two-stage least squares procedure for estimating a spatial autoregressive model with autoregressive disturbances. Journal of Real Estate Finance and Economics, 17, 99-121.

Kelejian, H. and I. Prucha (1999). A Generalized Moments Estimator for the Autoregressive Parameter in a Spatial Model. International Economic Review, 40, 509-533.

Kelejian, H. and I. Prucha (2007). HAC Estimation in a Spatial Framework. Journal of Econometrics, 140, 131-154.

Kelejian, H. and I. Prucha (2010). Specification and Estimation of Spatial Autoregressive Models with Autoregressive and Heteroskedastic Disturbances. Journal of Econometrics, 157, 53-67.

Keller, W. (2009). International Trade, Foreign Direct Investment, and Technology Spillovers. NBER Working Paper No. 15442.

Khandelwal, A. and P. Topalova (2011). Trade Liberalization and Firm Productivity: The Case of India. The Review of Economics and Statistics, 93(3), 995-1009.

Kleibergen, F. and R. Paap (2006). Generalized Reduced Rank Tests Using the Singular Value Decomposition. Journal of Econometrics, 133, 97-126.

Krishna, P. and D. Mitra (1998). Trade liberalization, market discipline and productivity growth: new evidence from India. Journal of Development Economics, 56, 447-462.

Kume, H., Piani, G. and C. F. Souza (2003). Instrumentos de Politica Comercial no Periodo 1987-1998 in Corseuil, C. H. and H. Kume (eds.) "A abertura comercial brasileira nos anos 1990: impactos sobre emprego e salário". Rio de Janeiro: Ipea.

López, R. A. (2005). Trade and Growth: Reconciling the macroeconomic and microeconomic evidence. Journal of Economic Surveys, 19(4), 623-648.

López, R. A. and J. Südekum (2009) Vertical industry relations, spillovers and productivity: evidence from Chilean plants. Journal of Regional Science, 49(4), 721-747.

López, R. A. and N. Yadav (2010). Imports of Intermediates Inputs and Spillover Effects: Evidence from Chilean Plants. The Journal of Development Studies, 46(8), 1385-1403.

Markusen, J. (1989). Trade in Producer Services and in Other Specialized Intermediate Inputs. American Economic Review, 79(1), 85-95.

Melitz, M. (2003). The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity. Econometrica, 71(6), 1695-1725.

Moreno, R., López-Bazo, E., Vayá, E. and M. Artís (2004). External Effects and Cost of Production. In Anselin, L., Florax, R. and Rey, S. (eds.) “Advances in Spatial Econometrics”. Berlin; New York: Springer-Verlag.

Muendler, M.-A. (2003). The Database Pesquisa Industrial Anual 1986-2001: A Detective's Report. Instituto Brasileiro de Geografia e Estatística, Rio de Janeiro, Mimeograph (econ.ucsd.edu/muendler/brazil).

Muendler, M.-A. (2004a). Trade, Technology, and Productivity: A Study of Brazilian Manufacturers, 1986-1998. CESifo Working Paper Series 1148.

Muendler, M.-A. (2004b). Estimating Production Functions When Efficiency Choice Is Endogenous. University of California, San Diego, Mimeograph.

Olley, G. and A. Pakes (1996). The Dynamics of Productivity in the Telecommunications Equipment Industry. Econometrica, 64(6), 1263-97.

Pavcnik, N. (2002). Trade Liberalization, Exit, and Productivity Improvement: Evidence from Chilean Plants. Review of Economic Studies, Wiley Blackwell, vol. 69(1), 245-76.

Pinkse, J. and M. E. Slade (2010). The Future of Spatial Econometrics. Journal of Regional Science, 50(1), 103-117.

Rosenthal, S. and W. Strange (2003). Geography, Industrial Organization and Agglomeration. Review of Economics and Statistics, 85, 377-393.

Schor, A. (2004). Heterogeneous Productivity Response to Tariff Reduction: Evidence from Brazilian Manufacturing Firms. Journal of Development Economics, 75(2), 373-96.

Stock, J. H. and M. Yogo (2002). Testing for Weak Instruments in Linear IV Regression. NBER Technical Working Papers 0284, National Bureau of Economic Research, Inc.

Van Beveren, I. (2011). Total Factor Productivity Estimation: A Practical Review. Journal of Economic Surveys, 26(1), 98-128.

Appendix: TFP Estimation Methodology

The first TFP measure (OLS-TFP) in Muendler (2004a) is the estimated OLS residual ($\widehat{\varepsilon_{it}}$) of a simplified production function, shown in equation (5).

$$y_{it} = \beta_{bl}^{ols} l_{it}^{bl} + \beta_{wh}^{ols} l_{it}^{wh} + \beta_{K}^{ols} k_{it} + \beta_{S}^{ols} s_{it} + \beta_{M}^{ols} m_{it} + \varepsilon_{it} \qquad (5)$$

where all variables are expressed in natural logarithms, and *y* is the output; l^{bl} is the number of blue-collar workers; l^{wh} is the number of white-collar workers; k is the stock of equipment; s is the stock of structures that encompasses real state, premises, vehicles, computers, and rented or leased capital goods; *m* is the amount of materials (intermediate inputs) used in production; and ε is the error term.

The second TFP measure (OP-TFP) in Muendler (2004a) is estimated using an extended version of the Olley and Pakes (1996) methodology, which was developed to address two well-known endogeneity problems that arise when estimating production functions. The first problem is the correlation between the unobservable productivity shocks (ω_{it}) included in the error term, and the quantities of inputs chosen by the firm. Notice that productivity shocks are assumed to be under the control of the firm's management but are unobservable by the researcher. When ignored, this correlation leads to inconsistent estimates if, for instance, OLS is used to estimate equation (5). The second problem is sample selection due to productivity levels, which occurs because firms that exit the market do so when their productivity (ω_{it}) falls below a certain level. As a result, the surviving firms' ω_{it} will come from a selected sample, which affects the level of inputs used. Muendler (2004a,b) extended the Olley-Pakes methodology to account for two types of investment in capital: equipment and structures. The production function used to estimate the OP-TFP measure is depicted by equation (6).

$$y_{it} = \beta_{bl} l_{it}^{bl} + \beta_{wh} l_{it}^{wh} + \beta_K k_{it} + \beta_s s_{it} + \beta_M m_{it} + \omega_{it} + \varepsilon_{it} \qquad (6)$$

Following the Olley-Pakes methodology, let both capital and structures be accumulated by firms through a deterministic dynamic investment process (I^K and I^S, respectively) that arises from the firm's profit maximization problem. These investment functions depend on time t state variables such as the current stock of capital (equipment or structures), current productivity, and variables representing not only the economic environment but also the firms' individual expectations about market demand. These latter variables ($\mathbf{D}_t$) that characterize a firm's environment are foreign market penetration, the economy-wide real exchange rate, nominal tariffs, aggregate demand, and the annual inflation rate. To prevent a simultaneity problem from changes in $\mathbf{D}_t$ due to changes in productivity, Muendler (2004a) uses the nominal exchange rate and foreign producer price indices at the sector level as instrumental variables to predict foreign market penetration and nominal tariffs. Since the investment functions are invertible, let ω_{it} be described by equation (7), where both β_{0i} and ξ_{it} are known to the firm when it chooses variable factor inputs and investments for the next period.

$$\omega_{it} = h\left(I_{it}^{k}, I_{it}^{s}, a_{it}, k_{it}, s_{it}, k_{it}^{F}; \boldsymbol{D}_{it}\right) + \beta_{0i} + \xi_{it} \tag{7}$$

Once ω_{it} is fully characterized, the TFP estimation strategy uses three regressions. The first regression equation is given by equation (8).

$$\begin{aligned} y_{it} \ = \ & \beta_{0i} + \beta_{bl} l_{it}^{bl} + \beta_{wh} l_{it}^{wh} + \beta_{M} m_{it} \\ & + \phi\left(I_{it}^{k}, I_{it}^{s}, a_{it}, k_{it}, s_{it}, k_{it}^{F}; \boldsymbol{D}_{it}\right) + \xi_{it} + \varepsilon_{it} \end{aligned} \tag{8}$$

where a polynomial series estimator of fourth-order approximates the following function: $\phi(.) \equiv \beta_{K} k_{it} + \beta_{s} s_{it} + h(\cdot)$. Each firm's individual productivity is estimated, which provides time-invariant industry-specific production function coefficients. So, within-industry variation is used to identify the coefficients of equation (8). Although this first regression provides consistent estimates for β_{0i}, β_{bl}, β_{wh}, and β_{M}, it does not identify the capital coefficients β_{K} and β_{S}.

The second regression, equation (9), focuses on the probability of a firm's survival, estimated using independent Logit functions for the pre-1991 and the post-1991 data, taking into account that the shutdown probabilities may have changed systematically after trade liberalization. Muendler (2004a) estimates probabilities over a fourth-order polynomial in $(I_{it}^{k}, I_{it}^{s}, a_{it}, k_{it}, s_{it}, k_{it}^{F})$ and $\mathbf{D}_t$.

$$\Pr(\chi_{it+1} = 1|.) = P\left(I_{it}^{k}, I_{it}^{s}, a_{it}, k_{it}, s_{it}, k_{it}^{F}; D_{it}\right) \tag{9}$$

A third-order polynomial expansion approximates the expectation of a survivor's productivity ω_{it+1} one period in advance, as shown below in equation (10),

$$\sum_{m=0}^{3}\sum_{n=0}^{3-m}\beta_{mn}(\hat{P})^{m}(\hat{h})^{n} \approx \int_{\underline{\omega}(k_{it},s_{it},\boldsymbol{D}_{t})}\omega_{it+1}\frac{f(\omega_{it+1}|\omega_{it})}{\Pr(\chi_{it+1}=1|.)}d\omega_{it+1} \tag{10}$$

where $\underline{\omega}(k_{it}, s_{it}, \boldsymbol{D}_t)$ is the smallest productivity level that a firm with capital k_{it} and s_{it} needs in order to stay in business under market conditions $\mathbf{D}_t$. The $\hat{P}$ term in the polynomial expansion is the Logit-predicted survival likelihood. The unknown productivity component $\hat{h}$ results from $\hat{h}(.) = \hat{\phi}(.) - \hat{\beta}_K k_{it+1} - \hat{\beta}_S s_{it+1}$. These considerations give rise to the third regression, equation (11). The equipment and structures coefficients (β_K and β_S) are estimated by non-linear least squares, using the estimates from firm fixed-effects regressions as starting values.

$$\begin{aligned} &y_{it+1} - \hat{\beta}_{0i} - \hat{\beta}_{bl}l_{it+1}^{bl} - \hat{\beta}_{wh}l_{it+1}^{wh} - \hat{\beta}_{M}m_{it+1} \\ &\qquad = \beta_K k_{it+1} + \beta_s s_{it+1} + \sum_{m=0}^{3}\sum_{n=0}^{3-m}\beta_{mn}(\hat{P})^{m}(\hat{h})^{n} + \eta_{it+1} \end{aligned} \tag{11}$$

Finally, with all the estimated coefficients, the ln OP-TFP at the firm level is given by

$$\ln(\widehat{OP-TFP_{it}}) = y_{it} - \bar{\beta}_J - \hat{\beta}_{bl}l_{it}^{bl} - \hat{\beta}_{wh}l_{it}^{wh} - \hat{\beta}_{M}m_{it} - \hat{\beta}_{K}k_{it} - \hat{\beta}_{s}s_{it}$$

where $\bar{\beta}_J$ is the average firm fixed effect that is defined as $\bar{\beta}_J \equiv \sum_{j\in S}^{J}\beta_{oj}/J$ and J is the number of firms in the industry. This eliminates confounding time-invariant demand conditions from ln(*OP-TFP*).

Table 1 – Correlation across TFP measures

Correlation/Sample	OLS-TFP All	OP-TFP All	OLS-TFP Stayers	OP-TFP Stayers
OLS-TFP All	1			
OP-TFP All	0.908	1		
OLS-TFP Stayers	0.999	0.905	1	
OP-TFP Stayers	0.907	0.999	0.906	1

All TFP variables are expressed in natural logarithms. OLS-TFP is the TFP obtained through the use of an OLS estimator, while OP-TFP is obtained by the Muendler (2004a,b) extended Olley-Pakes methodology. The "All" sample is an unbalanced panel of firms. The "Stayers" sample is a balanced panel of firms that were active throughout the trade liberalization period.

Table 2 – Descriptive Statistics

Variable	Number of Observations	Mean	Std. Dev.	Minimum	Maximum
OLS-TFP All	160	0.9865	0.0393	0.9127	1.1141
OP-TFP All	160	0.9987	0.0308	0.9177	1.0766
OLS-TFP Stayers	160	0.9867	0.0394	0.9133	1.1149
OP-TFP Stayers	160	0.9989	0.0307	0.9181	1.0765
Brazilian Output Tariff	160	0.2031	0.1212	0.040	0.750
Brazilian Input Tariff	160	0.2193	0.0998	0.0914	0.6818
Colombian Output Tariff	160	0.3193	0.1850	0.0649	1.199

All TFP variables are expressed in natural logarithms. OLS-TFP is the TFP obtained through the use of an OLS estimator, while OP-TFP is obtained by the Muendler (2004a,b) extended Olley-Pakes methodology. The "All" sample is an unbalanced panel of firms. The "Stayers" sample is a balanced panel of firms that were active throughout the trade liberalization period. Input tariffs are calculated according to equation (3).

Table 3 – First difference of the baseline specification, equation (1), estimated by instrumental variables

	Dependent variable					
	OLS-TFP	OLS-TFP	OLS-TFP	OP-TFP	OP-TFP	OP-TFP
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
ΔOutput Tariff	-0.208**		-0.225	-0.148**		-0.176
	(0.077)		(0.160)	(0.059)		(0.125)
ΔInput Tariff		-0.111	0.025		-0.066	0.040
		(0.100)	(0.174)		(0.077)	(0.135)
Joint test ΔOutput Tariff and ΔInput Tariff equal to zero			7.065**			6.23**
			[0.022]			[0.044]
Observations	160	160	160	160	160	160
1st Stage – ΔOutput tariff						
ΔOutput Colombian Tariff	0.328**		0.309**	0.328**		0.309**
	(0.056)		(0.057)	(0.056)		(0.057)
ΔInput Colombian Tariff			0.071			0.071
			(0.046)			(0.046)
1st Stage – Input Tariff						
ΔOutput Colombian Tariff			0.185**			0.185**
			(0.057)			(0.057)
ΔInput Colombian Tariff		0.203**	0.173**		0.203**	0.173**
		(0.046)	(0.046)		(0.046)	(0.046)
Weak id. Kleibergen-Paap rk Wald F statistic	33.69	19.31	2.596	33.69	19.31	2.596
Stock-Yogo 10% max TSLS size critical values	16.38	16.38	7.03	16.38	16.38	7.03
Endogeneity test	3.609*	1.571	5.301*	2.169	0.597	2.798
	[0.058]	[0.210]	[0.070]	[0.141]	[0.440]	[0.247]

All TFP variables are expressed in natural logarithms. Year dummy variables are included in all specifications. Colombian tariffs and input tariffs calculated using Colombian tariffs (if Brazilian input tariffs are included in the estimated specification) are used as excluded instruments. Robust standard errors are reported in parentheses. *p*-values are reported in brackets. ** and * indicate statistical significance at the 5% and 10% levels, respectively. The endogeneity test null hypothesis is that import tariff and input import tariff (if included in the estimated specification) are exogenous regressors.

Table 4 – Estimated effects of trade policy on industry-level TFP when inter-industry upstream spillovers are accounted for by estimating equation (2) using the Generalized Spatial Instrumental Variable estimator.

	Dependent variable					
	OLS-TFP	OLS-TFP	OLS-TFP	OP-TFP	OP-TFP	OP-TFP
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
Spatial lag (WΔTFP)	0.696**	0.656*	0.597**	0.780**	0.814***	0.666**
	(0.316)	(0.354)	(0.286)	(0.274)	(0.308)	(0.243)
ΔOutput Tariff	-0.178**		-0.192	-0.125**		-0.117
	(0.059)		(0.124)	(0.045)		(0.091)
ΔInput Tariff		-0.220**	0.050		-0.170**	0.004
		(0.094)	(0.181)		(0.072)	(0.131)
Error Spatial correlation			-0.293			-0.347
			(0.335)			(0.396)
Joint test ΔOutput Tariff and ΔInput Tariff equal to zero			8.76**			7.15**
			[0.013]			[0.028]
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	160	160	160	160	160	160

All TFP variables are expressed in natural logarithms. Colombian tariffs and input tariffs calculated using Colombian tariffs (if Brazilian input tariffs are included in the estimated specification) are used as excluded instruments in addition to Kelejian and Prucha's (1998) instruments. Standard errors are reported in parentheses. ** and * indicate statistical significance at the 5% and 10% levels, respectively.

Table 5 – TFP upstream spillovers accounted for by estimating equation (2) using the Generalized Spatial Instrumental Variable estimator with heteroskedastic robust standard errors.

	Dependent variable					
	OLS-TFP	OLS-TFP	OLS-TFP	OP-TFP	OP-TFP	OP-TFP
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
Spatial lag (WΔTFP)	0.696**	0.656**	0.579**	0.780**	0.814***	0.670**
	(0.279)	(0.277)	(0.235)	(0.250)	(0.265)	(0.199)
ΔOutput Tariff	-0.178**		-0.165**	-0.125**		-0.101**
	(0.062)		(0.068)	(0.051)		(0.051)
ΔInput Tariff		-0.220	0.011		-0.170	-0.069
		(0.146)	(0.150)		(0.113)	(0.089)
Error Spatial correlation			-0.532**			-0.464**
			(0.217)			(0.196)
Joint test ΔOutput Tariff and			9.56**			6.34**
ΔInput Tariff equal to zero			[0.008]			[0.042]
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	160	160	160	160	160	160

All TFP variables are expressed in natural logarithms. Colombian tariffs and input tariffs calculated using Colombian tariffs (if Brazilian input tariffs are included in the estimated specification) are used as excluded instruments in addition to Kelejian and Prucha's (1998) instruments. Robust standard errors calculated according to Kelejian and Prucha (2007) are reported in parentheses. ** and * indicate statistical significance at the 5% and 10% levels, respectively.

Table 6 – Estimated effects of trade policy on industry-level TFP when inter-industry downstream spillovers are accounted for by estimating equation (2) using the Generalized Spatial Instrumental Variable estimator.

	Dependent variable					
	OLS-TFP	OLS-TFP	OLS-TFP	OP-TFP	OP-TFP	OP-TFP
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
Spatial lag (WΔTFP)	0.317	0.269	0.328	0.461	0.460	0.469**
	(0.415)	(0.495)	(0.296)	(0.356)	(0.403)	(0.203)
ΔOutput Tariff	-0.147**		-0.071	-0.107**		-0.092
	(0.063)		(0.114)	(0.050)		(0.069)
ΔInput Tariff		-0.246**	-0.162		-0.170*	-0.052
		(0.118)	(0.196)		(0.090)	(0.118)
Error Spatial correlation			-0.875			-1.375*
			(0.918)			(0.802)
Joint test ΔOutput Tariff and			6.89**			7.79**
ΔInput Tariff equal to zero			[0.032]			[0.020]
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	160	160	160	160	160	160

All TFP variables are expressed in natural logarithms. Colombian tariffs and input tariffs calculated using Colombian tariffs (if Brazilian input tariffs are included in the estimated specification) are used as excluded instruments in addition to Kelejian and Prucha's (1998) instruments. Robust standard errors calculated according to Kelejian and Prucha (2007) are reported in parentheses. ** and * indicate statistical significance at the 5% and 10% levels, respectively.

Table 7 – TFP upstream spillovers accounted for by estimating equation (2) using the Generalized Spatial Instrumental Variable estimator with heteroskedastic robust standard errors and controls for market competitiveness.

	Dependent variable			
	OLS-TFP	OLS-TFP	OP-TFP	OP-TFP
Independent variables	(1)	(2)	(3)	(4)
Spatial lag (WΔTFP)	0.688**	0.545**	0.723**	0.685**
	(0.293)	(0.241)	(0.244)	(0.203)
ΔOutput Tariff	-0.100	-0.115	-0.030	-0.045
	(0.113)	(0.091)	(0.094)	(0.078)
Herfindahl* ΔOutput Tariff	-0.127	-0.106	-0.216	-0.185
	(0.222)	(0.185)	(0.147)	(0.130)
ΔInput Tariff	-0.127	-0.070	-0.119	-0.086
	(0.114)	(0.100)	(0.089)	(0.079)
Error Spatial correlation		-0.496**		-0.377*
		(0.241)		(0.193)
Joint test ΔOutput Tariff, Herfindahl* ΔOutput Tariff, and ΔInput Tariff equal to zero	8.67** [0.034]	9.82** [0.020]	7.36* [0.061]	7.46* [0.059]
Year dummies	Yes	Yes	Yes	Yes
Observations	160	160	160	160

All TFP variables are expressed in natural logarithms. Colombian tariffs and input tariffs calculated using Colombian tariffs (if Brazilian input tariffs are included in the estimated specification) are used as excluded instruments in addition to Kelejian and Prucha's (1998) instruments. Robust standard errors calculated according to Kelejian and Prucha (2007) are reported in parentheses. ** and * indicate statistical significance at the 5% and 10% levels, respectively.

Table 8 – Falsification test (placebo estimates) of the effects of trade policy on industry-level TFP when upstream inter-industry spillovers are accounted for by estimating equation (2) using the Generalized Spatial Instrumental Variable estimator.

	Dependent variable					
	OLS-TFP	OLS-TFP	OLS-TFP	OP-TFP	OP-TFP	OP-TFP
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)
Spatial lag (WΔTFP)	-0.029	-0.060	-0.006	0.213	0.341	0.355
	(0.302)	(0.317)	(0.303)	(0.271)	(0.231)	(0.243)
ΔOutput Tariff	-0.142**	-0.141**	-0.101	-0.098**	-0.100**	-0.050
	(0.056)	(0.056)	(0.104)	(0.044)	(0.044)	(0.081)
ΔInput Tariff			-0.077			-0.098
			(0.163)			(0.126)
Error Spatial correlation		0.087	-0.042		-0.294	-0.306
		(0.357)	(0.436)		(0.454)	(0.481)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	160	160	160	160	160	160

All TFP variables are expressed in natural logarithms. Colombian tariffs and input tariffs calculated using Colombian tariffs (if Brazilian input tariffs are included in the estimated specification) are used as excluded instruments in addition to Kelejian and Prucha's (1998) instruments. The spatial weighting matrix used here was randomly generated. Standard errors are reported in parentheses. ** and * indicate statistical significance at the 5% and 10% levels, respectively.