Trade policy reform and firm-level productivity growth: Does the choice of production function matter?

John Kealey* Pau S. Pujolàs César Sosa-Padilla

July 7, 2016

Abstract

This paper considers whether a fairly well-established empirical relationship between liberalized trade and firm productivity growth is sensitive to the choice of an identification strategy for production function estimation. We estimate the productivity of Colombian manufacturing plants using the methods of Levinsohn and Petrin (2003), Ackerberg, Caves, and Frazer (2006), and Gandhi, Navarro, and Rivers (2012), and at times come to surprisingly different conclusions about the country's experience with trade policy reform during the 1980s. Results from a quantile regression model and a productivity growth decomposition exercise tend to vary as we experiment with different specifications of the production function. Research that is concerned with the short and medium-term impact of trade liberalization on domestic manufacturing industries should therefore pay close attention to issues of robustness to alternative strategies for estimating the productivity of firms.

1 Introduction

Contemporary theories of international trade tend to advance the point of view that import competition is beneficial for the productivity of domestic firms. From this perspective, one of the key advantages of a liberalized trade policy environment is that, by expanding the availability of foreign-produced goods, it encourages innovation among local producers who do not wish to see their market share erode. This, in turn, has a modernizing effect on

*John Kealey gratefully acknowledges support from the Social Sciences and Humanities Council of Canada.

the home country's industrial landscape. The need for empirical validation of the aforementioned theoretical stance has, in recent decades, given rise to a vast literature that is concerned with estimating the influence that trade barriers have on the dynamics of firm productivity. Of course, it is important to recognize that any serious discussion pertaining to the productivity of firms needs to be grounded in a well-thought-out methodological framework that allows for proper idenfication of an underlying production function. While many empirical researchers acknowledge this fact, they rarely give sufficient consideration to the sensitivity of their findings to their chosen strategy for identifying and estimating firm productivity. Hence this paper considers three different identification strategies that are commonly employed for the estimation of production functions, namely those of Levinsohn and Petrin (2003), Ackerberg et al. (2006), and Gandhi et al. (2012), and examines whether they yield consistent conclusions vis-à-vis firm-level productivity growth during periods of trade liberalization. Using data from the Colombian manufacturing sector, which has appeared in a number of related studies in the past, we find that switching from a "control function" Cobb-Douglas specification to a more flexible nonparametric framework tends to alter our findings regarding certain industries' experience with trade policy reforms.

A fair amount of evidence can be found in the empirical literature of a negative association between barriers to trade and firm productivity. For instance, Tybout and Westbrook (1995), Pavcnik (2002), Schor (2004), Fernandes (2007), Topalova and Khandelwal (2011), and Hu and Liu (2014) demonstrate that the liberalization of trade policy has generally coincided with productivity growth at the firm-level in Mexico, Chile, Brazil, Colombia, India, and China, respectively. The empirical focus of these studies tends to be the conditional mean of firm productivity, given different levels of trade protection; that is, most authors employ linear regression methods to evaluate whether there exists a rather general relationship between trade policy on the one hand, and the conditional expectation of firm productivity on the other. However, results that are obtained using standard linear regression techniques fail to shed light on whether different types of firms, ranging from the least to the most efficient producers of a particular good, exhibit similar responses to changes in the policy environment. Thus, in the present paper, we opt for a quantile regression approach that is better able to reflect trends in the *distribution* of firm productivity, as opposed to its conditional mean, during Colombia's era of liberalization. From a theoretical point of view, it makes sense to focus on outcomes at different quantiles because there is likely some intra-industry variation in the effect that competition from trade has on innovation behaviour and productivity. Indeed, Melitz (2003) posits that open trade enhances productivity through three distinct channels, namely i) reallocation of resources and market share from inefficient to efficient producers, ii) market exit on the part of inefficient firms, and iii) market entry on the part of efficient firms. Melitz and Polanec (2015) build on previous work by Olley and Pakes (1996) and propose a decomposition procedure that allows for the empirical isolation of these contributing factors to aggregate productivity growth. We apply this methodology to each of the Levinsohn-Petrin (LP), Ackerberg-Caves-Frazer (ACF), and Gandhi-Navarro-Rivers (GNR) productivity estimates and set out to identify any overlap that exists in our results. It turns out that our decomposition of industry-level productivity growth into the effects of market share reallocation among incumbents, exit of inefficient producers, and entry of productive firms is quite sensitive to the chosen identification strategy for estimation of the production function.

The remainder of the paper is structured as follows: section 2 provides a thorough summary of the three different methods that we employ to estimate firm-level productivity in the Colombian manufacturing sector. Section 3 describes the input, output, and trade policy data that is used in the analysis in section 4, where we discuss the coefficient estimates that we obtain under several specifications of our quantile regression model, and the results of the Melitz-Polanec decomposition exercise that we perform for a long list of manufacturing industries. Section 5 concludes.

2 A review of methods to estimate firm productivity

In this section, we provide a thorough overview of three different strategies for the identification and estimation of firm-level productivity. These approaches, which are presented in the chronological order of their appearance in the productivity literature, were originally proposed by Levinsohn and Petrin (2003), Ackerberg et al. (2006), and Gandhi et al. (2012), and are now in widespread use in a number of different subfields of empirical economics. In what follows, we adopt the convention whereby lower-case (upper-case) letters are used to denote the log (level) values of the variables in the production model.

2.1 Levinsohn and Petrin's control function method

Consider a logarithmically-transformed Cobb-Douglas production function:

$$y_{it} = \alpha_k k_{it} + \alpha_l l_{it} + \alpha_m m_{it} + \omega_{it} + \varepsilon_{it} \tag{1}$$

where y_{it} is the log of firm i's gross output in period t, k_{it} is the capital stock, l_{it} is the quantity of labour employed by the firm, and m_{it} is an intermediate input variable comprising raw materials and energy consumption. Firm-level productivity is denoted by ω_{it} and ε_{it} is a random error term. Levinsohn and Petrin (2003) propose a "control function" approach whereby the firm's intermediate input demand is a function of its capital stock and its level of productivity:

$$m_{it} = m\left(k_{it}, \omega_{it}\right) \tag{2}$$

Assuming that the function $m\left(\cdot\right)$ is strictly increasing in ω_{it} holding k_{it} fixed, one can invert (2) to obtain an expression for firm-level productivity:

$$\omega_{it} = m^{-1}\left(k_{it}, m_{it}\right) \tag{3}$$

Inserting (3) into (1) yields:

$$\begin{aligned} y_{it} &= \alpha_k k_{it} + \alpha_l l_{it} + \alpha_m m_{it} + m^{-1}\left(k_{it}, m_{it}\right) + \varepsilon_{it} \\ &= \alpha_l l_{it} + \theta\left(k_{it}, m_{it}\right) + \varepsilon_{it} \end{aligned} \tag{4}$$

where $\theta\left(k_{it}, m_{it}\right) = \alpha_k k_{it} + \alpha_m m_{it} + m^{-1}\left(k_{it}, m_{it}\right)$. One can specify $\theta\left(k_{it}, m_{it}\right)$ as a third-order polynomial in k_{it} and m_{it} and estimate (4) by means of an ordinary least squares regression. This yields an estimate of the elasticity of output with respect to labour, $\hat{\alpha}_l$.

Next, Levinsohn and Petrin's (2003) framework assumes that firm-level productivity evolves according to a first-order Markov process:

$$\omega_{it} = g\left(\omega_{it-1}\right) + \eta_{it} \tag{5}$$

where η_{it} can be interpreted as an unanticipated productivity shock. Using the fitted values $\hat{\theta}\left(k_{it}, m_{it}\right)$ from the regression in (4), one can obtain the following expression for ω_{it}:

$$\omega_{it}\left(\alpha_k, \alpha_m\right) = \hat{\theta}\left(k_{it}, m_{it}\right) - \alpha_k k_{it} - \alpha_m m_{it} \tag{6}$$

Lagged productivity, $\omega_{it-1}\left(\alpha_k, \alpha_m\right)$, is analogously defined. We specify (5) as a third-order polynomial without an intercept $\omega_{it} = \rho_1 \omega_{it-1} + \rho_2 \omega_{it-1}^2 + \rho_3 \omega_{it-1}^3 + \eta_{it}$ and estimate ρ_1, ρ_2, and ρ_3 for given values of α_k and α_m, which allows us to write the unanticipated productivity shock as a function of the unknown elasticity parameters $\eta_{it}\left(\alpha_k, \alpha_m\right)$. Levinsohn and Petrin (2003) use the following moment condition to identify the elasticity of output with respect to capital and intermediate inputs:

$$\mathbb{E}\left[\eta_{it}\left(\alpha_k, \alpha_m\right) | k_{it}, m_{it-1}\right] = 0 \tag{7}$$

Finally, $\hat{\alpha}_k$ and $\hat{\alpha}_m$ can be plugged into (6) to obtain firm i's period-t productivity, $\hat{\omega}_{it}$.

2.2 Ackerberg, Caves, and Frazer's value-added model

Ackerberg et al. (2006) point out that Levinsohn and Petrin's (2003) approach suffers from a multicollinearity issue stemming from the likelihood that a firm's labour and intermediate input decisions are both influenced by its level of productivity. They show how this can complicate estimation of α_l in the partially linear model that is depicted in (4), and as an alternative, they propose the following value-added Cobb-Douglas production model:

$$va_{it} = \alpha_k k_{it} + \alpha_l l_{it} + \omega_{it} + \varepsilon_{it} \tag{8}$$

where now, va_{it} denotes firm i's value-added output in period-t. The right-hand side of (8) is the same as in (1), with the exception that the intermediate input variable m_{it} has been omitted. Ackerberg et al. (2006) use the same control function as Levinsohn and Petrin (2003) that appears in (3), and rewrite (8) as:

$$\begin{aligned} va_{it} &= \alpha_k k_{it} + \alpha_l l_{it} + m^{-1}\left(k_{it}, m_{it}\right) + \varepsilon_{it} \\ &= \phi\left(k_{it}, l_{it}, m_{it}\right) + \varepsilon_{it} \end{aligned} \tag{9}$$

Note that the central difference between the current approach and the one described in section 2.1 lies in the specification of $\phi\left(k_{it}, l_{it}, m_{it}\right)$ in (9) as opposed to that of $\theta\left(k_{it}, l_{it}, m_{it}\right)$ in (4). Once again, $\phi\left(k_{it}, l_{it}, m_{it}\right)$ can be specified as a third-order polynomial in k_{it}, l_{it}, and m_{it} and estimated via OLS. Productivity can then be written as $\omega_{it}\left(\alpha_k, \alpha_l\right) = \hat{\phi}\left(k_{it}, l_{it}, m_{it}\right) - \alpha_k k_{it} - \alpha_l l_{it}$ and the productivity shock η_{it} in (5) can be expressed in terms of the unknown elasticity parameters $\eta_{it}\left(\alpha_k, \alpha_l\right)$ by following the same procedure that was described in the previous subsection. Finally, Ackerberg et al. (2006) use the following moment condition to identify α_k and α_l:

$$\mathbb{E}\left[\eta_{it}\left(\alpha_k, \alpha_l\right) | k_{it}, l_{it-1}\right] = 0 \tag{10}$$

Firm-level productivity is then given by $\hat{\omega}_{it} = \hat{\phi}\left(k_{it}, l_{it}, m_{it}\right) - \hat{\alpha}_k k_{it} - \hat{\alpha}_l l_{it}$.

2.3 Gandhi, Navarro, and Rivers' nonparametric identification strategy

Gandhi et al. (2012) show how one can estimate a production function whose underlying functional form is unknown:

$$Y_{it} = F\left(K_{it}, L_{it}, M_{it}\right) e^{\omega_{it} + \varepsilon_{it}} \tag{11}$$

where the upper-case Y_{it}, K_{it}, L_{it}, and M_{it} denote the output, capital stock, labour, and intermediate input variables in level form. Meanwhile, the productivity and error terms are once again denoted by ω_{it} and ε_{it}, respectively. Gandhi et al.'s (2012) approach makes use of the firm's first-order condition for its choice of intermediate inputs:

$$p_M = p_Y F_M \left(K_{it}, L_{it}, M_{it}\right) e^{\omega_{it}} E\left[e^{\varepsilon_{it}}\right] \tag{12}$$

where p_M and p_Y are respectively the intermediate input and final output prices and $F_M\left(K_{it}, L_{it}, M_{it}\right)$ is the partial derivative of the production function with respect to the intermediate input variable. Next, it can be shown that if one subtracts the log of (11) from the log of (12) and subsequently adds the log of M_{it} to both sides of the resulting expression, one obtains:

$$\ln\left(\frac{p_M M_{it}}{p_Y Y_{it}}\right) = \ln\left(\frac{F_M\left(K_{it}, L_{it}, M_{it}\right) M_{it}}{F\left(K_{it}, L_{it}, M_{it}\right)} E\left(e^{\varepsilon_{it}}\right)\right) - \varepsilon_{it} \tag{13}$$

The left-hand side of (13) can be computed using firm-level input expenditure and revenue data, while the expression in parentheses on the right-hand side can be approximated by a second-order polynomial in k_{it}, l_{it}, and m_{it} (lower case letters denote the logs of the input variables). The equation can then be estimated by means of a non-linear least squares regression, and this yields estimates of ε_{it}, $E\left(e^{\varepsilon_{it}}\right)$, and $\frac{F_M(K_{it},L_{it},M_{it})M_{it}}{F(K_{it},L_{ji},M_{it})}$.

As a next step in the process of identifying a firm's production function, Gandhi et al. (2012) make use of the equality $\frac{F_M(K_{it},L_{it},M_{it})}{F(K_{it},L_{it},M_{it})} = \frac{\partial}{\partial M_{it}} \ln F\left(K_{it}, L_{it}, M_{it}\right)$. Integrating both sides of this expression gives us

$$\int \frac{F_M\left(K_{it}, L_{it}, M_{it}\right) M_{it}}{F\left(K_{it}, L_{it}, M_{it}\right)} \frac{\mathrm{d}M_{it}}{M_{it}} = \ln F\left(K_{it}, L_{it}, M_{it}\right) + \mathscr{C}\left(K_{it}, L_{it}\right) \tag{14}$$

Given that $\frac{F_M(K_{it},L_{it},M_{it})M_{it}}{F(K_{it},L_{it},M_{it})}$ has already been identified and estimated in (13), the expression above makes it possible to identify $\ln F\left(K_{it}, L_{it}, M_{it}\right)$ up to a constant of integration, which Gandhi et al. (2012) denote by $\mathscr{C}\left(K_{it}, L_{it}\right)$.[1] Combining (14) and the log of (11), the firm-

[1] Note that the integral has a straightforward closed-form solution because a second-order polynomial approximation was used to estimate $\frac{F_M(K_{it},L_{it},M_{it})M_{it}}{F(K_{it},L_{it},M_{it})}$.

level productivity term ω_{it} satisfies the following equality:

$$\omega_{it} = \ln Y_{it} - \int \frac{F_M\left(K_{it}, L_{it}, M_{it}\right) M_{it}}{F\left(K_{it}, L_{it}, M_{it}\right)} \frac{\mathrm{d}M_{it}}{M_{it}} - \varepsilon_{it} + \mathscr{C}\left(K_{it}, L_{it}\right) \tag{15}$$

For the sake of notational simplicity, the above expression is rewritten as

$$\omega_{it} = \mathcal{Y}_{it} + \mathscr{C}\left(K_{it}, L_{it}\right) \tag{16}$$

where $\mathcal{Y}_{it}$ is shorthand for the more cumbersome $\ln Y_{it} - \int \frac{F_M(K_{it}, L_{it}, M_{it}) M_{it}}{F(K_{it}, L_{it}, M_{it})} \frac{\mathrm{d}M_{it}}{M_{it}} - \varepsilon_{it}$. Lagged productivity, ω_{it-1}, is analogously defined. The constant of integration is modelled as a second-order polynomial in k_{it} and l_{it}. Once again, we can follow the same procedure that was described in sections 2.1 and 2.2 and model the evolution of ω_{it} as a first-order Markov process $\omega_{it} = \rho_1 \omega_{it-1} + \rho_2 \omega_{it-1}^2 + \rho_3 \omega_{it-1}^3 + \eta_{it}$. The moment condition $E\left(\eta_{it} | K_{it}, L_{it}, \mathcal{Y}_{it-1}, K_{it-1}, L_{it-1}\right) = 0$ identifies the parameters in $\mathscr{C}\left(K_{it}, L_{it}\right)$, yielding an estimate of firm-level productivity ω_{it}.

3 Data

The dataset that underlies the analysis in section 4 is taken from a census of Colombian manufacturers whose participants include all plants with 10 or more employees over the 11-year period 1981-1991. It consists of more than 61,000 observations on nearly 11,000 plants in 22 different industries. Note that while industries are classified according to their 3-digit ISIC code, they can be further subdivided on the basis of the 71 unique 4-digit ISIC codes that appear in the sample. The primary advantage of using the Colombian manufacturing data is that it has appeared in previous empirical studies that examine the relationship between trade and firm-level productivity (Roberts and Tybout, 1997; Fernandes, 2007). The gross ouput, value-added, capital stock, and intermediate input variables are all expressed in thousands of Colombian pesos, and are deflated using an industry-by-year price index that is found in the data.[2] Intermediate inputs, which are included in the production functions

[2] In particular, both the nominal and the real value of production is recorded for each observation in the panel of manufacturing plants and hence, the ratio of these two variables serves as an industry-level price index.

of Levinsohn and Petrin (2003) and Gandhi et al. (2012) but absent from that of Ackerberg et al. (2006), are defined as the total amount of energy and raw materials consumed by a plant in a given year. A plant's value-added production is therefore obtained by subtracting its intermediate input consumption from its gross output. Meanwhile, the labour variable is expressed as the total number of workers that are on a plant's payroll, but with the slight modification that unskilled and skilled labourers are weighted by the ratio of their respective median salaries.

The trade policy predictor that appears in our regression model is measured in two different ways. First, we use the Colombian government's import tariff schedule that is available for each of the 71 unique 4-digit ISIC codes that are represented in the census. For the 11-year period that runs from 1981 to 1981, tariff data is missing for 1982 and 1989-1991, and so the first specification of the regression model is estimated using a 7-year subsample of the original dataset. In addition to the tariff data, we also use the effective rate of protection (ERP) as a trade policy indicator. This is intended to reflect the dual impact of protectionism, i.e. reduced competition from abroad on the one hand and increased imported input costs on the other. The ERP is computed as $\frac{va_d - va_w}{va_w}$, where va_d and va_w respectively denote manufacturers' value-added under distorted domestic (d) and undistorted world (w) prices. The effective rate of protection data is available for 22 unique 3-digit ISIC codes for the years 1981, 1984, 1985, 1990, and 1991, and so once again, the regressions that include the ERP as a predictor are only carried out on a 5-year subsample of the data. Tables 1 and 2 shed some light on the extent to which Colombia's trade policy regime underwent reform during the period that is under consideration. Minimum and maximum tariff and ERP values are reported for each of the 3-digit and 4-digit industries that are covered by the sample. In many instances, there is substantial liberalization, with some industries experiencing a 50 to 60 percentage point decrease in import tariffs between the mid-1980s and the early-1990s. In fact, in the textile industry, the difference between the min and max ERP is about 120 percentage points, which constitutes quite an aggressive policy reform over a relatively short timeframe.

4 Trade liberalization and firm productivity: A few results

Before proceeding with our discussion of the dynamics of firm-level productivity before and after Colombia's trade policy reforms, a couple of brief comments on the productivity estimates themselves might be in order. First, the ACF, GNR, and LP identification strategies often give rise to surprisingly different productivity estimates. In table 4, we report industry-level Spearman correlations for the three alternative measures. We find that there is a fair amount of positive comovement between the ACF and GNR estimates, whereas their respective pairwise correlations with the LP measure tend to be much lower and even negative at times. This is quite a remarkable outcome, particularly since the Spearman correlation coefficients are intended to reflect the extent to which the ranking of firms' productivity remains consistent across the three identification strategies. An additional point that is worth mentioning is that the ACF, GNR, and LP productivity estimates do not exhibit the same amount of dispersion. Given that the first of these is based on a value-added model, it displays more heterogeneity than the latter two which arise from a gross output specification of the production function. Industry-level coefficients of variation for the three estimates are reported in table 3. Now that we are aware of these differences in characteristics across the ACF, GNR, and LP measures of productivity, we are ready to move on to a summary of the main results of this paper. In section 4.1, we discuss the output of a simple quantile regression model in which the dependent and independent variables are firm-level productivity and an industry-level indicator of trade policy, respectively. In section 4.2, we apply the methodological framework of Melitz and Polanec (2015) and quantify the relative contributions of incumbent firms, new entrants, and exiting firms to industry-level productivity growth as Colombia switched from a protectionist to a more liberalized trade policy regime during the 1980s.

4.1 Quantile regression coefficient estimates

In table 5, we report coefficient estimates for a number of different specifications of a quantile regression model in which the log of firm productivity and the 4-digit industry-level import tariff are the dependent and explanatory variables, respectively. For each of the LP, ACF, and GNR measures of productivity, we estimate three equations - one that includes an industry dummy, another that includes both an industry and a time dummy, and finally, one where consideration is limited to industries that are categorized as "import-competing". This latter categorization has been applied in previous studies that examine the empirical link between trade policy and productivity, most notably in Pavcnik (2002), who defines a 4-digit industry as import-competing if the ratio of imports to total output exceeds a particular threshold. The author experiments with different cutoff values and finds that her results remain fairly consistent when the ratio lies between 0.10 and 0.25. In her final analysis, she settles on 0.15, which is the value that we use here as well.

Three key findings in table 5 are worth emphasizing. First the sign of the quantile regression coefficient estimates displays a fair amount of sensitivity to the manner in which the production function has been specified. In columns 1-6 where the log of the LP and ACF productivity estimates are the dependent variables, most of the coefficient estimates - especially those that correspond to the median, upper quartile, and top decile - are negative. However, when the Cobb-Douglas specification of LP and ACF is replaced by the nonparametric framework of GNR in columns 7-9, we often observe a *positive* association between import tariffs and firm productivity. Second, regardless of whether the LP, ACF, or GNR estimation procedures are employed, there is more of an adverse association between the tariff rate and firm-level productivity in the right tail than in the left tail of the distribution of firms. Evidence of this phenomenon can be seen in pretty much every single column of table 5, where the regression coefficient estimates tend to be in decline as one moves downward from the row that corresponds to the 0.10^{th} quantile to the one that corresponds to the 0.90^{th} quantile. Hence, much of the productivity growth that was experienced during Colombia's era of trade liberalization appears to have taken place among firms who were already among the most efficient in their respective industries. Third, when we restrict our attention to import-competing industries, which constitues about one-quarter of the sample, we find some evidence of a negative relationship between import tariffs and the top three quantiles of the GNR productivity estimates. We also observe moderate increases in the coefficient estimates for the bottom decile, lower quartile, and median of the LP and ACF measures of firm productivity.

Next, we re-estimate the nine quantile regression models that have just been discussed, but where the effective rate of protection (ERP) now serves as the indicator of trade policy. The results are reported in table 6. In this instance, we observe a similar pattern to what was noted in the previous paragraph. The negative association between the ERP and productivity becomes more pronounced as one moves closer to the right-tail of the distribution of firms. Thus, during the period of trade liberalization from the mid-1980s to the early-1990s, the most productive firms seem to have made the greatest efficiency gains, and this finding holds across each of the LP, ACF, or GNR identification strategies. In addition, there is an interesting point of divergence between the regression models that use the tariff rate and the ERP, respectively, as the explanatory variable reflecting the trade policy regime. While the former yields positive and statistically significant coefficient estimates for the lower-half of the distribution of GNR productivity, the latter gives rise to coefficient estimates that are either negative or quite small in magnitude relative to their standard errors (or both). This suggests that of the three different measures of productivity that are considered in this paper, the one that relies on the most flexible (i.e. nonparametric) specification of the production function exhibits a more ambiguous statistical relationship with the indicators of trade protectionism than the measures arising from a more traditional linearized Cobb-Douglas functional form.

4.2 Decomposition of aggregate productivity changes

Melitz and Polanec (2015) build on previous work by Olley and Pakes (1996) and outline a framework for the decomposition of industry-level productivity changes into the respective contributions of surviving firms, new entrants, and exiting firms. In the present context, let $t \in \{H, L\}$ denote a time period that is characterized by either a high (H) or a low (L) tariff regime, and let $j \in \{S, X, E\}$ denote the group to which firm i belongs, namely either survivors (S), exiters (X), or entrants (E). Note that in the Colombian manufacturing data, the high-tariff period generally precedes the low-tariff period, and hence the exiting firms and new entrants only appear in the sample in periods H and L, respectively. Let ω_{ijt} denote firm i's productivity and let s_{ijt} represent its share of industry-level output under tariff regime t, where the subscript j serves to indicate that firm i belongs to group j. Thus, group j's share of aggregate output in period t is given by $s_{jt} = \sum_i s_{ijt}$ and its aggregate productivity is computed as $\Phi_{jt} = \sum_i \frac{s_{ijt}}{s_{jt}} \omega_{ijt}$. Melitz and Polanec (2015) then show that aggregate industry-level productivity under the tariff regimes H and L can be written as:

$$\Phi_H = s_{SH}\Phi_{SH} + s_{XH}\Phi_{XH}$$

$$\Phi_L = s_{SL}\Phi_{SL} + s_{EL}\Phi_{EL}$$

This gives rise to the following decomposition of the change in aggretate productivity $\Delta\Phi$ when an industry's trade policy regime switches from H to L:

$$\begin{aligned} \Delta\Phi &= (\Phi_{SL} - \Phi_{SH}) + s_{EL}(\Phi_{EL} - \Phi_{SL}) + s_{XH}(\Phi_{SH} - \Phi_{XH}) \\ &= \Delta\bar{\omega}_S + \Delta\text{cov}_S + s_{EL}(\Phi_{EL} - \Phi_{SL}) + s_{XH}(\Phi_{SH} - \Phi_{XH}) \end{aligned} \tag{17}$$

where $\Delta\bar{\omega}_S$ denotes the change in the mean productivity of surviving firms, Δcov_S denotes the change in the covariance of surviving firms' productivity and their share of total output, and $s_{EL}(\Phi_{EL} - \Phi_{SL})$ and $s_{XH}(\Phi_{SH} - \Phi_{XH})$ respectively capture the effects of entry of more productive firms and exit of less productive firms in the intervening period between the high tariff and low tariff regimes. Thus, Melitz and Polanec's (2015) framework makes it possible to test some of the theoretical predictions that are found in Melitz (2003) and quantify the relative importance of four distinct channels through which trade liberalization is believed to affect industry-level productivity.

Tables 7 through 10 contain the raw results of the decomposition exercise that has been performed using the LP, ACF, and GNR measures of productivity. All of the reported values have been normalized by setting $\Phi_H = 1$ for each industry. Two different samples - respectively comprising the years in which import tariffs and the effective rate of protection attain their max and min values - are once again used for the analysis.[3] Given that the large volume of the raw results makes them somewhat difficult to interpret, we provide a simplified summary of some of the key findings in tables 11 through 13. To begin, in table 11, we report the frequency with which the aggregate and decomposed estimates of firm productivity growth exhibit a positive sign, as might be predicted by modern trade theory. Regardless of whether the tariff rate or the ERP is used as the indicator of protectionism, the first column shows that aggregate ACF productivity experiences positive change with the greatest frequency; in this instance, the sign of $\Delta\Phi$ is greater than zero in nearly three-quarters of the industries that appear in the sample. On the other hand, when the 3-digit industry-level change in ERP is considered, aggregate LP productivity growth is positive only half of the time. In regard to the decomposed growth estimates, we find that efficiency gains among surviving firms ($\Delta\bar{\omega}_S$), efficient reallocation of market share among incumbents (Δcov_S), and the exit of inefficient firms ($s_{XH}(\Phi_{SH} - \Phi_{XH})$) tend to play a more important role than the entry of productive firms into the market ($s_{EL}(\Phi_{EL} - \Phi_{SL})$). While the latter is characterized by a positive sign in less than half of the industries in our sample, its magnitude is generally very small, and hence we conclude that it rarely makes any noteworthy contribution to industry-level productivity growth.

Tables 12 and 13 shed light on the consistency of the results of the decomposition exercise across the LP, ACF, and GNR productivity measures. The former includes Spearman correlations of the three estimates of each of the growth components in (17), while the latter reports on a pairwise basis the frequency with which they display the same expected positive sign. Here, we observe one of this paper's more interesting results, namely that there is far less uniformity than might originally have been anticipated in the dynamics of the LP, ACF, and GNR estimates as Colombia shifted from a protectionist to a more liberalized trade policy regime. The Spearman correlations in table 12 are quite modest and in some

[3]The max of both tariffs and the ERP tends to be observed in the mid-1980s, while the min tends to be observed in either the late 1980s (tariffs) or the early 1990s (ERP), due to differences in data availability.

cases, are actually negative. The decomposition procedure gives rise to particularly different outcomes under the LP and GNR identification strategies. Table 13 reflects a similar tendency whereby under the very best scenario, the various components of productivity growth only exhibit the same sign across the different measures of productivity in about half of the industries in the sample. Moreover, this finding does not change when we move from the 4-digit industry-level tariff to the 3-digit industry-level ERP as the trade policy indicator in the model. Hence, any judgement about the relative contributions of incumbent firms, exiters, and new entrants to industry-level productivity growth ultimately depends on the underlying specification of the production function. If we wish to evaluate the performance of firms and industries subsequent to trade policy reforms, it is therefore imperative that we keep in mind the sensitivity of the Melitz-Polanec framework in (17) to the choice of a Cobb-Douglas functional form vs. a more flexible nonparametric alternative.

5 Conclusion

This paper has applied three commonly-used strategies for identifying production functions and has examined whether a consistent pattern emerges vis-à-vis the dynamics of firm productivity during periods of trade policy reform in the Colombian manufacturing sector. It has found that the statistical association between productivity and both the nominal and effective rate of protection is rather sensitive to the chosen production function estimation procedure. Switching from a value-added to a gross output model, or from a Cobb-Douglas "control function" framework to a more flexible nonparametric specification tends to alter the results of our quantile regression model and of the productivity growth decomposition exercise that we perform for a number of manufacturing industries. This raises questions about whether previous empirical findings in the productivity and trade literature are robust to alternative specifications of the production function. Extending our analysis to other firm-level datasets offers interesting possibilities for future research.

References

Ackerberg, D., K. Caves, and G. Frazer (2006): "Structural identification of production functions," Mpra paper, University Library of Munich, Germany.

Fernandes, A. (2007): "Trade policy, trade volumes and plant-level productivity in Colombian manufacturing industries," *Journal of International Economics*, 71, 52–71.

Gandhi, A., S. Navarro, and D. Rivers (2012): "On the identification of production functions: How heterogeneous is productivity?" 2012 Meeting Papers 105, Society for Economic Dynamics.

Hu, A. G. and Z. Liu (2014): "Trade liberalization and firm productivity: Evidence from Chinese manufacturing industries," *Review of International Economics*, 22, 488–512.

Levinsohn, J. and A. Petrin (2003): "Estimating production functions using inputs to control for unobservables," *Review of Economic Studies*, 70, 317–341.

Melitz, M. J. (2003): "The impact of trade on intra-industry reallocations and aggregate industry productivity," *Econometrica*, 71, 1695–1725.

Melitz, M. J. and S. Polanec (2015): "Dynamic Olley-Pakes productivity decomposition with entry and exit," *RAND Journal of Economics*, 46, 362–375.

Olley, S. G. and A. Pakes (1996): "The dynamics of productivity in the telecommunications equipment industry," *Econometrica*, 64, 1263–97.

Pavcnik, N. (2002): "Trade liberalization, exit, and productivity improvements: Evidence from Chilean plants," *Review of Economic Studies*, 69, 245–276.

Roberts, M. and J. Tybout (1997): "The decision to export in Colombia: An empirical model of entry with sunk costs," *American Economic Review*, 87, 545–64.

Schor, A. (2004): "Heterogeneous productivity response to tariff reduction: Evidence from Brazilian manufacturing firms," *Journal of Development Economics*, 75, 373–396.

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

Tybout, J. R. and M. D. Westbrook (1995): "Trade liberalization and the dimensions of efficiency change in Mexican manufacturing industries," *Journal of International Economics*, 39, 53–78.

ISIC	min tariff	max tariff	ISIC	min tariff	max tariff
3111	0.265	0.411	3513	0.266	0.398
3112	0.298	0.470	3521	0.288	0.463
3113	0.413	0.653	3522	0.092	0.139
3114	0.285	0.446	3523	0.367	0.637
3115	0.170	0.401	3529	0.214	0.343
3116	0.260	0.382	3551	0.181	0.274
3117	0.375	0.620	3559	0.397	0.585
3118	0.169	0.289	3560	0.490	0.812
3119	0.000	0.633	3620	0.269	0.430
3121	0.259	0.415	3691	0.218	0.351
3122	0.090	0.110	3692	0.136	0.224
3131	0.568	0.930	3699	0.280	0.453
3132	0.488	0.798	3710	0.185	0.288
3133	0.325	0.475	3811	0.337	0.559
3134	0.400	0.660	3812	0.400	0.797
3211	0.403	0.815	3813	0.252	0.449
3212	0.655	1.224	3819	0.326	0.550
3213	0.672	1.331	3821	0.089	0.205
3214	0.700	1.255	3822	0.059	0.189
3215	0.450	0.721	3823	0.152	0.270
3219	0.460	0.806	3824	0.162	0.271
3220	0.657	1.217	3825	0.220	0.476
3231	0.191	0.336	3829	0.236	0.417
3232	0.425	0.425	3831	0.254	0.474
3233	0.464	0.775	3832	0.226	0.329
3240	0.564	0.934	3833	0.365	1.005
3311	0.382	0.604	3839	0.284	0.468
3312	0.445	0.735	3841	0.173	0.287
3319	0.358	0.592	3842	0.197	0.496
3320	0.400	0.823	3843	0.367	0.578
3411	0.223	0.369	3844	0.404	0.772
3412	0.392	0.647	3845	0.101	0.198
3419	0.308	0.482	3849	0.371	0.613
3420	0.362	0.511	3851	0.196	0.314
3511	0.180	0.290	3852	0.208	0.329
3512	0.054	0.128	Pooled	0.000	1.331

Table 1: Import tariffs in the Colombian manufacturing sector 1981-1988 (4-digit ISIC).

ISIC	min ERP	max ERP	ISIC	min ERP	max ERP
311	0.791	1.470	352	0.250	0.413
313	0.574	1.349	355	0.536	1.004
321	0.826	2.033	356	0.712	1.467
322	0.734	1.900	362	0.360	0.561
323	0.441	0.990	369	0.383	0.625
324	0.821	1.674	371	0.242	0.395
331	0.649	1.182	381	0.585	0.988
332	0.565	1.371	382	0.163	0.372
341	0.415	0.668	383	0.370	0.815
342	0.360	0.595	384	0.504	1.058
351	0.208	0.378	385	0.224	0.428

Table 2: Effective rate of protection in the Colombian manufacturing sector 1981-1991 (3-digit ISIC).

ISIC	LP	ACF	GNR	ISIC	LP	ACF	GNR
311	0.651	1.280	0.258	352	0.369	0.739	0.203
313	0.051	0.840	0.407	355	0.281	0.564	0.342
321	1.745	0.489	0.199	356	0.333	0.581	0.148
322	0.352	0.586	0.147	362	0.154	0.464	0.230
323	0.431	0.562	0.123	369	0.204	0.829	0.254
324	0.449	0.485	0.114	371	0.180	0.659	0.297
331	0.144	0.376	0.148	381	0.101	0.529	0.157
332	0.147	0.308	0.137	382	1.393	0.771	0.219
341	0.235	2.249	0.222	383	0.098	0.583	0.178
342	0.175	0.458	0.144	384	0.114	0.602	0.258
351	0.164	0.736	0.234	385	0.369	0.590	0.169

Table 3: Coefficient of variation of LP, ACF, and GNR productivity estimates by industry.

	LP	ACF	GNR		LP	ACF	GNR
311				**352**			
LP	1			LP	1		
ACF	0.355	1		ACF	0.181	1	
GNR	-0.402	-0.794	1	GNR	0.093	0.875	1
313				**355**			
LP	1			LP	1		
ACF	0.341	1		ACF	0.557	1	
GNR	0.338	0.885	1	GNR	0.517	0.891	1
321				**356**			
LP	1			LP	1		
ACF	0.639	1		ACF	-0.058	1	
GNR	0.384	0.802	1	GNR	-0.303	0.858	1
322				**362**			
LP	1			LP	1		
ACF	0.306	1		ACF	0.083	1	
GNR	0.249	0.887	1	GNR	-0.321	0.750	1
323				**369**			
LP	1			LP	1		
ACF	0.624	1		ACF	0.209	1	
GNR	0.478	0.779	1	GNR	0.033	0.829	1
324				**371**			
LP	1			LP	1		
ACF	0.289	1		ACF	-0.003	1	
GNR	-0.070	0.724	1	GNR	-0.369	0.809	1
331				**381**			
LP	1			LP	1		
ACF	-0.418	1		ACF	0.197	1	
GNR	-0.705	0.819	1	GNR	-0.008	0.885	1
332				**382**			
LP	1			LP	1		
ACF	0.284	1		ACF	0.023	1	
GNR	-0.203	0.743	1	GNR	-0.055	0.944	1
341				**383**			
LP	1			LP	1		
ACF	0.328	1		ACF	0.248	1	
GNR	0.134	0.881	1	GNR	0.255	0.938	1
342				**384**			
LP	1			LP	1		
ACF	0.176	1		ACF	0.170	1	
GNR	-0.073	0.802	1	GNR	0.129	0.844	1
351				**385**			
LP	1			LP	1		
ACF	0.267	1		ACF	-0.416	1	
GNR	-0.103	0.755	1	GNR	-0.787	0.701	1

Table 4: Spearman correlations of productivity estimates by 3-digit industry.

		LP			ACF			GNR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
q_{10}	-0.0048	-0.0067	-0.0014	-0.0153	0.0440	0.1258	0.1240	0.2352	0.0789
	(0.0014)	(0.0016)	(0.0047)	(0.0185)	(0.0224)	(0.0637)	(0.0191)	(0.0238)	(0.0637)
q_{25}	-0.0112	-0.0150	0.0031	-0.0798	-0.0302	0.0638	0.0896	0.1934	0.0454
	(0.0025)	(0.0031)	(0.0083)	(0.0155)	(0.0187)	(0.0522)	(0.0134)	(0.0168)	(0.0402)
q_{50}	-0.0341	-0.0477	0.0049	-0.1675	-0.1485	-0.0323	0.0459	0.1211	-0.0077
	(0.0044)	(0.0053)	(0.0135)	(0.0166)	(0.0204)	(0.0529)	(0.0090)	(0.0108)	(0.0319)
q_{75}	-0.0730	-0.0964	-0.0427	-0.2402	-0.2249	-0.2303	0.0130	0.0600	-0.0775
	(0.0074)	(0.0091)	(0.0210)	(0.0204)	(0.0261)	(0.0722)	(0.0068)	(0.0084)	(0.0300)
q_{90}	-0.1112	-0.1419	-0.1410	-0.3535	-0.3740	-0.2699	0.0097	0.0420	-0.0723
	(0.0151)	(0.0181)	(0.0414)	(0.0318)	(0.0379)	(0.1139)	(0.0075)	(0.0093)	(0.0367)
3-digit ISIC effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
year effects		yes			yes			yes	
import-competing			yes			yes			yes
N	38,297	38,297	8,478	38,297	38,297	8,478	38,297	38,297	8,478

Table 5: Quantile regression output where tariff rate is the trade policy indicator (standard errors in parentheses). Dependent variable is log of plant-level productivity. Data available for years 1981, 1983-1988.

		LP			ACF			GNR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
q_{10}	-0.0018	-0.0011	-0.0005	-0.0157	-0.0057	0.0212	-0.0027	0.0399	-0.0610
	(0.0009)	(0.0013)	(0.0032)	(0.0107)	(0.0152)	(0.0409)	(0.0132)	(0.0176)	(0.0376)
q_{25}	-0.0052	-0.0055	0.0085	-0.0228	-0.0122	0.0128	-0.0064	0.0266	0.0017
	(0.0016)	(0.0022)	(0.0062)	(0.0101)	(0.0143)	(0.0334)	(0.0090)	(0.0124)	(0.0309)
q_{50}	-0.0113	-0.0158	0.0020	-0.0459	-0.0506	-0.0210	-0.0117	-0.0008	0.0056
	(0.0027)	(0.0038)	(0.0102)	(0.0110)	(0.0152)	(0.0358)	(0.0058)	(0.0081)	(0.0215)
q_{75}	-0.0241	-0.0335	-0.0138	-0.1032	-0.1110	-0.0973	-0.0126	-0.0006	-0.0375
	(0.0046)	(0.0064)	(0.0152)	(0.0144)	(0.0193)	(0.0455)	(0.0042)	(0.0061)	(0.0197)
q_{90}	-0.0415	-0.0627	0.0104	-0.1362	-0.1317	-0.1612	-0.0159	-0.0075	-0.0174
	(0.0097)	(0.0137)	(0.0275)	(0.0230)	(0.0315)	(0.0747)	(0.0044)	(0.0061)	(0.0225)
3-digit ISIC effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
year effects		yes			yes			yes	
import-competing			yes			yes			yes
N	27,177	27,177	6,287	27,177	27,177	6,287	27,177	27,177	6,287

Table 6: Quantile regression output where ERP is the trade policy indicator (standard errors in parentheses). Dependent variable is log of plant-level productivity. Data available for years 1981, 1984, 1985, 1990, 1991.

ISIC	$\Delta\Phi$	$\Delta\bar{\omega}_S$	Δcov_S	$s_{XH}\,(\Phi_{SH}-\Phi_{XH})$	$s_{EL}\,(\Phi_{EL}-\Phi_{SL})$
3111	0.109	0.275	-0.162	-0.001	-0.003
3112	0.187	0.060	0.123	0.012	-0.008
3113	-0.048	0.000	-0.052	0.006	-0.001
3114	0.007	-0.055	0.031	0.011	0.019
3115	0.069	0.109	-0.043	0.006	-0.004
3116	0.109	-0.039	0.165	0.012	-0.028
3117	0.020	0.007	0.009	0.008	-0.005
3118	0.017	-0.017	0.035	-0.001	-0.001
3119	0.080	0.039	0.049	0.014	-0.023
3121	0.054	0.021	0.029	0.005	-0.001
3122	0.115	0.044	0.077	0.007	-0.013
3131	0.033	0.005	0.026	0.002	0.000
3132	0.001	0.018	-0.016	0.001	-0.001
3133	0.016	0.003	0.013	0.000	0.000
3134	0.014	-0.001	0.016	0.000	-0.001
3211	0.050	0.019	0.004	0.013	0.014
3212	0.039	-0.024	0.044	0.010	0.009
3213	-0.003	-0.008	0.009	0.001	-0.006
3214	-0.028	-0.034	0.009	0.000	-0.004
3215	-0.023	-0.009	-0.014	0.000	0.000
3219	-0.145	0.007	-0.146	0.005	-0.011
3220	-0.003	-0.01	0.011	0.006	-0.010
3231	0.053	0.068	-0.018	0.001	0.002
3233	0.092	0.361	-0.257	-0.007	-0.005
3240	0.045	-0.048	0.09	0.017	-0.015
3311	-0.012	-0.002	-0.023	0.034	-0.020
3312	-0.053	-0.004	-0.025	0.000	-0.023
3319	-0.007	-0.038	0.027	-0.004	0.008
3320	0.001	-0.011	0.034	-0.005	-0.016
3411	-0.048	-0.005	-0.039	-0.005	0.000
3412	0.064	0.030	0.040	0.005	-0.011
3419	-0.010	0.008	0.003	-0.015	-0.006
3420	0.037	-0.004	0.042	-0.003	0.003
3511	0.030	0.015	-0.006	0.001	0.020
3512	0.026	0.060	-0.048	0.004	0.010
3513	-0.006	0.028	-0.048	0.004	0.010
3521	0.113	0.033	0.092	0.005	-0.018
3522	-0.017	0.008	-0.030	-0.001	0.006
3523	-0.032	0.012	0.019	-0.002	-0.061
3529	0.037	0.029	0.010	0.001	-0.003
3551	-0.052	0.019	-0.071	0.003	-0.003
3559	0.000	0.004	-0.008	0.013	-0.009
3560	0.07	-0.003	0.035	0.001	0.038
3620	-0.062	-0.014	-0.051	-0.001	0.004
3691	-0.003	-0.013	0.005	-0.001	0.006
3692	0.044	0.041	0.038	-0.030	-0.005
3699	0.106	0.021	0.145	-0.074	0.015
3710	0.033	-0.015	0.045	0.003	0.000
3811	0.004	0.001	0.002	0.003	-0.002
3812	-0.024	0.009	-0.028	-0.002	-0.003
3813	-0.011	0.001	-0.014	0.006	-0.004
3819	-0.024	0.002	-0.027	-0.001	0.002
3821	-0.014	-0.003	-0.012	0.000	0.000
3822	-0.005	-0.071	0.071	0.002	-0.007
3823	-0.535	-0.006	-0.004	-0.532	0.006
3824	0.001	0.005	0.006	-0.004	-0.006
3825	0.038	0.002	0.041	0.007	-0.013
3829	0.023	0.017	0.013	-0.004	-0.003
3831	0.019	0.019	0.002	0.003	-0.005
3832	0.022	0.011	0.009	0.007	-0.006
3833	0.016	0.014	-0.008	0.006	0.004
3839	0.013	-0.002	0.015	0.002	-0.002
3841	0.004	0.003	-0.045	0.002	0.045
3842	-0.014	-0.043	0.008	0.028	-0.006
3843	0.005	0.017	-0.011	0.003	-0.004
3844	0.018	-0.022	0.021	0.039	-0.020
3845	-0.130	-0.055	-0.074	0.000	-0.001
3849	0.018	0.043	-0.021	0.000	-0.004
3851	0.028	-0.025	0.045	-0.004	0.011
3852	-0.032	-0.170	0.136	-0.004	0.006

Table 7: Melitz-Polanec decomposition of LP productivity growth following tariff cut.

ISIC	$\Delta\Phi$	$\Delta\bar{\omega}_S$	Δcov_S	$s_{XH}\,(\Phi_{SH}-\Phi_{XH})$	$s_{EL}\,(\Phi_{EL}-\Phi_{SL})$
3111	0.136	0.053	0.058	-0.024	0.049
3112	0.095	0.074	0.021	0.029	-0.029
3113	-0.251	-0.020	-0.243	0.010	0.002
3114	-0.230	-0.077	-0.004	-0.130	-0.018
3115	-0.152	-0.079	-0.073	0.004	-0.004
3116	0.125	0.032	0.117	0.015	-0.039
3117	-0.030	0.074	-0.109	0.005	0.000
3118	-0.113	-0.015	-0.091	-0.002	-0.005
3119	0.118	0.087	0.128	-0.038	-0.059
3121	0.110	0.103	0.022	0.004	-0.020
3122	0.040	0.029	0.022	-0.015	0.003
3131	0.233	0.046	0.176	0.012	-0.001
3132	-0.108	-0.212	0.104	0.012	-0.012
3133	0.303	0.314	-0.010	-0.001	0.000
3134	-0.049	-0.105	0.048	0.011	-0.002
3211	0.165	0.045	0.023	0.019	0.078
3212	0.265	0.000	0.324	0.015	-0.073
3213	0.007	-0.008	0.021	0.004	-0.008
3214	-0.093	-0.108	0.015	0.000	0.000
3215	0.050	0.064	-0.014	0.000	0.000
3219	0.013	0.094	-0.066	0.006	-0.021
3220	0.133	-0.017	0.179	0.009	-0.037
3231	-0.074	0.123	-0.168	-0.033	0.005
3233	0.015	-0.031	0.026	-0.039	0.059
3240	0.015	0.023	-0.028	0.018	0.002
3311	-0.093	0.014	-0.037	-0.037	-0.033
3312	0.341	0.182	0.055	0.000	0.103
3319	0.034	0.047	-0.003	0.008	-0.018
3320	0.288	0.077	0.338	-0.012	-0.115
3411	0.043	0.256	-0.199	-0.010	-0.004
3412	0.096	0.046	0.067	0.019	-0.035
3419	0.005	-0.137	0.234	-0.083	-0.008
3420	0.001	0.065	-0.071	0.003	0.005
3511	0.090	0.025	-0.032	-0.027	0.124
3512	0.077	0.228	-0.198	0.012	0.034
3513	0.381	0.205	0.220	-0.078	0.034
3521	0.395	0.096	0.404	-0.040	-0.065
3522	0.440	0.020	0.053	-0.014	0.382
3523	0.093	0.071	0.063	0.004	-0.046
3529	0.175	0.208	-0.001	-0.009	-0.023
3551	0.187	0.063	0.127	0.006	-0.009
3559	0.122	0.044	0.076	0.013	-0.011
3560	0.134	0.014	0.039	0.005	0.077
3620	0.067	-0.022	0.012	-0.002	0.078
3691	0.012	0.021	-0.031	0.021	0.001
3692	0.061	-0.050	0.118	0.004	-0.010
3699	0.067	0.032	0.066	-0.119	0.089
3710	0.163	0.155	0.001	0.011	-0.003
3811	0.177	0.135	0.040	-0.002	0.004
3812	1.924	0.074	2.248	-0.027	-0.370
3813	0.296	0.129	0.076	-0.023	0.114
3819	0.287	0.077	0.213	0.019	-0.022
3821	-0.244	-0.126	-0.118	0.000	0.000
3822	-0.116	-0.066	-0.014	0.004	-0.040
3823	-0.017	0.050	-0.066	-0.094	0.093
3824	0.104	0.073	0.010	0.001	0.020
3825	0.504	0.406	0.317	-0.114	-0.105
3829	0.289	0.174	0.171	0.116	-0.171
3831	0.443	0.228	0.213	-0.007	0.009
3832	0.113	0.041	0.065	0.015	-0.008
3833	0.927	0.054	0.096	0.018	0.760
3839	0.212	0.096	0.118	0.002	-0.004
3841	0.402	0.192	0.472	-0.004	-0.258
3842	-0.326	-0.346	-0.009	0.019	0.009
3843	-0.044	0.034	-0.075	0.007	-0.011
3844	-0.053	-0.080	0.050	0.242	-0.267
3845	-0.265	0.114	-0.375	0.000	-0.004
3849	0.063	0.130	-0.074	0.000	0.007
3851	0.918	0.038	0.250	0.004	0.626
3852	-0.080	-0.011	-0.078	0.000	0.009

Table 8: Melitz-Polanec decomposition of ACF productivity growth following tariff cut.

ISIC	$\Delta\Phi$	$\Delta\bar{\omega}_S$	Δcov_S	$s_{XH}\,(\Phi_{SH}-\Phi_{XH})$	$s_{EL}\,(\Phi_{EL}-\Phi_{SL})$
3111	-0.009	-0.028	0.039	0.016	-0.036
3112	-0.017	-0.013	-0.003	-0.014	0.014
3113	-0.108	-0.011	-0.108	0.012	0.000
3114	-0.080	-0.080	-0.125	0.127	-0.002
3115	0.027	-0.011	0.032	0.002	0.003
3116	0.022	-0.029	0.051	-0.015	0.014
3117	0.068	-0.007	0.084	-0.010	0.001
3118	-0.077	-0.017	-0.062	0.001	0.001
3119	-0.051	-0.006	-0.046	-0.008	0.009
3121	-0.043	-0.027	-0.025	0.001	0.008
3122	-0.060	-0.051	-0.014	0.003	0.002
3131	0.182	0.052	0.119	0.012	-0.001
3132	-0.077	-0.163	0.066	0.007	0.013
3133	0.032	-0.072	0.103	0.000	0.000
3134	0.042	-0.051	0.082	0.014	-0.003
3211	0.031	0.000	0.021	0.016	-0.006
3212	0.010	-0.045	0.023	0.011	0.020
3213	-0.007	0.001	0.000	-0.004	-0.004
3214	-0.034	-0.015	-0.018	0.000	-0.002
3215	0.008	0.012	-0.004	0.000	0.000
3219	-0.010	0.050	-0.057	0.001	-0.005
3220	-0.010	-0.006	-0.005	0.003	-0.001
3231	0.135	0.072	0.057	0.001	0.005
3233	-0.014	-0.026	0.028	-0.023	0.008
3240	-0.035	0.03	-0.074	-0.003	0.011
3311	-0.028	-0.002	0.001	-0.009	-0.018
3312	0.147	0.071	0.030	0.000	0.046
3319	0.032	0.021	0.014	0.008	-0.011
3320	0.048	0.025	0.031	-0.002	-0.005
3411	0.030	0.056	-0.024	-0.004	0.002
3412	0.078	0.059	0.020	0.006	-0.008
3419	0.108	0.024	0.110	-0.022	-0.004
3420	0.068	0.064	0.016	-0.022	0.010
3511	-0.026	-0.009	-0.001	-0.005	-0.010
3512	-0.002	-0.029	0.029	0.003	-0.005
3513	0.071	0.024	0.056	-0.011	0.003
3521	0.130	-0.006	0.147	0.009	-0.020
3522	0.017	0.003	0.010	-0.007	0.011
3523	-0.017	0.038	0.037	0.003	-0.095
3529	0.048	0.057	0.000	0.002	-0.011
3551	0.277	0.073	0.208	0.003	-0.007
3559	0.081	0.018	0.068	-0.002	-0.003
3560	0.004	0.009	0.003	-0.006	-0.001
3620	0.245	0.064	0.143	-0.011	0.050
3691	0.032	-0.015	0.029	0.023	-0.006
3692	0.203	0.116	0.042	0.050	-0.0053
3699	0.102	0.026	0.098	-0.033	0.010
3710	0.090	0.084	0.005	0.006	-0.006
3811	0.079	0.063	0.017	-0.001	0.000
3812	0.033	0.017	0.029	-0.012	-0.002
3813	0.135	0.050	0.069	-0.011	0.028
3819	0.019	-0.001	0.010	0.008	0.001
3821	-0.050	-0.048	-0.002	0.000	0.000
3822	-0.026	-0.024	0.018	0.003	-0.023
3823	-0.013	0.021	-0.033	-0.067	0.066
3824	0.069	0.045	0.016	0.000	0.009
3825	-0.006	-0.008	0.045	-0.050	0.006
3829	0.098	0.063	0.059	0.021	-0.045
3831	0.097	0.026	0.054	0.001	0.017
3832	0.015	-0.003	0.011	0.008	-0.001
3833	0.093	0.019	0.080	0.009	-0.014
3839	0.049	0.043	0.014	0.004	-0.012
3841	0.287	0.120	0.421	-0.004	-0.250
3842	-0.275	-0.267	-0.011	0.010	-0.007
3843	0.076	0.033	0.046	0.000	-0.003
3844	0.021	-0.043	0.050	-0.057	0.071
3845	-0.341	-0.036	-0.302	0.000	-0.003
3849	0.024	0.002	0.034	0.000	-0.012
3851	-0.027	-0.010	0.024	0.005	-0.046
3852	-0.059	-0.004	-0.048	0.002	-0.009

Table 9: Melitz-Polanec decomposition of GNR productivity growth following tariff cut.

ISIC	$\Delta\Phi$	$\Delta\bar{\omega}_S$	$\Delta\mathrm{cov}_S$	$s_{XH}\,(\Phi_{SH}-\Phi_{XH})$	$s_{EL}\,(\Phi_{EL}-\Phi_{SL})$
			Levinsohn-Petrin		
311	0.078	0.024	0.059	-0.001	-0.003
313	-0.019	0.000	-0.030	0.008	0.003
321	-0.013	0.018	-0.008	-0.014	-0.008
322	0.108	0.021	0.068	0.041	-0.022
323	0.052	0.252	-0.206	0.011	-0.006
324	0.127	-0.013	0.137	0.017	-0.014
331	0.077	0.001	0.082	0.023	-0.029
332	0.013	0.032	0.002	-0.003	-0.019
341	0.016	0.011	0.006	-0.001	0.000
342	0.046	-0.017	0.054	-0.002	0.011
351	-0.024	0.000	-0.034	0.008	0.001
352	0.010	0.016	0.021	-0.004	-0.023
355	-0.064	0.086	-0.152	0.009	-0.007
356	0.023	0.018	0.012	-0.006	-0.001
362	-0.073	0.000	-0.078	0.002	0.004
369	0.069	0.023	0.087	-0.047	0.006
371	-0.131	-0.064	-0.082	0.011	0.003
381	-0.017	0.005	-0.02	-0.001	0.000
382	-0.075	0.010	0.020	-0.085	-0.02
383	-0.008	-0.005	-0.009	0.006	0.000
384	-0.006	0.007	-0.018	0.007	-0.002
385	0.202	0.036	0.141	-0.003	0.029
			Ackerberg-Caves-Frazer		
311	-0.358	-0.128	-0.246	-0.019	0.036
313	-0.108	-0.02	-0.200	0.075	0.037
321	0.117	0.071	0.095	-0.020	-0.029
322	0.350	0.067	0.182	0.142	-0.041
323	-0.069	0.058	-0.127	-0.010	0.01
324	1.186	0.105	1.396	0.047	-0.361
331	0.674	0.085	0.640	0.068	-0.118
332	0.101	0.056	0.067	0.014	-0.035
341	0.055	0.002	0.058	0.000	-0.005
342	0.047	0.073	-0.023	-0.018	0.014
351	0.003	-0.025	0.026	-0.028	0.029
352	0.017	0.089	-0.030	-0.006	-0.035
355	-0.170	-0.018	-0.160	0.017	-0.01
356	-0.039	-0.056	0.013	0.011	-0.007
362	-0.074	-0.08	-0.069	0.008	0.068
369	0.013	-0.013	0.068	-0.077	0.035
371	0.089	-0.010	0.094	0.011	-0.005
381	0.289	-0.028	0.332	0.003	-0.019
382	0.224	0.232	0.156	-0.072	-0.092
383	0.021	-0.027	0.037	0.020	-0.01
384	0.051	-0.040	0.103	-0.029	0.017
385	0.176	-0.042	0.063	0.018	0.137
			Gandhi-Navarro-Rivers		
311	0.018	-0.001	0.000	0.024	-0.005
313	-0.079	-0.012	-0.153	0.079	0.007
321	0.017	0.003	0.020	0.006	-0.012
322	0.019	-0.001	0.013	0.015	-0.008
323	0.101	0.010	0.091	0.000	-0.001
324	0.084	-0.003	0.068	0.007	0.012
331	0.092	0.023	0.063	0.017	-0.011
332	0.032	-0.010	0.038	0.008	-0.004
341	0.033	0.037	-0.010	0.000	0.006
342	0.067	0.068	-0.023	-0.019	0.041
351	-0.028	-0.017	-0.004	-0.002	-0.005
352	0.000	0.034	0.003	-0.001	-0.036
355	-0.204	0.051	-0.262	0.008	0.000
356	-0.013	-0.028	0.011	0.003	0.000
362	0.172	0.013	0.119	-0.007	0.047
369	0.146	0.023	0.109	0.006	0.007
371	0.058	0.034	0.027	0.003	-0.005
381	0.013	-0.025	0.029	-0.001	0.01
382	0.089	0.110	0.001	-0.016	-0.006
383	0.010	-0.021	0.031	0.005	-0.005
384	-0.056	-0.015	-0.053	-0.005	0.017
385	-0.080	-0.061	-0.015	0.008	-0.012

Table 10: Melitz-Polanec decomposition of productivity growth following ERP cut.

	$\Delta\Phi$	$\Delta\bar{\omega}_S$	Δcov_S	$s_{XH}\,(\Phi_{SH}-\Phi_{XH})$	$s_{EL}\,(\Phi_{EL}-\Phi_{SL})$
Δ *Tariff*					
LP	0.614	0.571	0.600	0.600	0.314
ACF	0.743	0.729	0.629	0.543	0.400
GNR	0.614	0.529	0.700	0.514	0.400
ΔERP					
LP	0.545	0.727	0.545	0.500	0.455
ACF	0.727	0.455	0.682	0.545	0.409
GNR	0.682	0.500	0.682	0.682	0.455

Table 11: Proportion of industry-level productivity changes that have expected positive sign.

Δ *Tariff*				ΔERP			
$\Delta\Phi$							
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.221	1		ACF	0.260	1	
GNR	0.102	0.523	1	GNR	0.133	0.221	1
$\Delta\bar{\omega}_S$							
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.293	1		ACF	-0.112	1	
GNR	0.147	0.435	1	GNR	-0.032	0.596	1
Δcov_S							
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.198	1		ACF	0.390	1	
GNR	-0.110	0.482	1	GNR	0.065	0.328	1
$s_{XH}\,(\Phi_{SH}-\Phi_{XH})$							
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.312	1		ACF	0.571	1	
GNR	0.072	0.443	1	GNR	0.294	0.609	1
$s_{EL}\,(\Phi_{EL}-\Phi_{SL})$							
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.468	1		ACF	0.819	1	
GNR	-0.019	0.208	1	GNR	0.444	0.320	1

Table 12: Spearman correlation of component-wise LP, ACF, and GNR productivity growth.

	$\Delta\,Tariff$				$\Delta\,ERP$		
			$\Delta\Phi$				
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.493	1		ACF	0.409	1	
GNR	0.423	0.535	1	GNR	0.409	0.545	1
			$\Delta\bar{\omega}_S$				
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.500	1		ACF	0.364	1	
GNR	0.343	0.471	1	GNR	0.364	0.318	1
			Δcov_S				
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.429	1		ACF	0.409	1	
GNR	0.414	0.529	1	GNR	0.409	0.500	1
			$s_{XH}\left(\Phi_{SH} - \Phi_{XH}\right)$				
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.400	1		ACF	0.364	1	
GNR	0.371	0.400	1	GNR	0.364	0.455	1
			$s_{EL}\left(\Phi_{EL} - \Phi_{SL}\right)$				
	LP	ACF	GNR		LP	ACF	GNR
LP	1			LP	1		
ACF	0.225	1		ACF	0.273	1	
GNR	0.155	0.239	1	GNR	0.273	0.227	1

Table 13: Frequency with which the pairwise LP, ACF, and GNR productivity growth components have the same expected positive sign.