Trade Liberalization, Firm Heterogeneity, and Unemployment: An Empirical Investigation

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Abstract

This paper provides empirical evidence for the interaction between firm-level total factor productivity and trade liberalization as key determinants of firm-level job destruction caused by trade. We also test some key theoretical predictions from Melitz (2003), whose model we use to derive an explicit equation for the relationship between firm productivity and trade-induced unemployment when a country liberalizes its trade policy. Employing US firm-level data, we find strong empirical support for the following: a) All else equal, a one-percent increase in total factor firm productivity decreases trade-induced layoffs by 32%; b) An additional percent of trade liberalization increases the number of firm-level trade-induced layoffs by 2%; c) Trade liberalization results in an increase in the minimum level of productivity required for domestic production; d) Trade liberalization lowers the minimum productivity threshold required for exporting; e) The increase due to trade liberalization, in the minimum productivity threshold for domestic production is larger than the absolute decrease in the export productivity threshold.

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1 Introduction

Following Melitz (2003), a fast growing literature has been studying the consequences of heterogeneous firms for the effects of trade and trade liberalization.[1] Many of these studies have clear structural predictions about the relationship between trade liberalization, and firm-level trade-induced unemployment when firms differ in their total factor productivity. Despite the interest in the role of heterogeneity however, many of the theoretical implications and relationships of the Melitz's model have not yet been tested empirically. In this paper, we make an attempt to narrow this gap by providing empirical evidence for the interaction between firm productivity, and trade liberalization in the determination of firm-level, trade-induced unemployment.

Melitz (2003) develops a dynamic industry model with heterogeneous firms to examine the intra-industry effects of international trade. He finds that opening to trade causes the least productive firms to stop producing and the more productive firms to start exporting, since only the more productive firms can bear the fixed trade costs. As a result, market shares are reallocated toward more productive firms, which leads to an aggregate productivity increase and an increase in the zero-profit productivity cutoff, defined as the minimum productivity level needed for a firm to produce domestically. Melitz also shows that trade liberalization results in an increase in zero-profit productivity cutoff and a decrease in the export productivity cutoff, defined as the minimum productivity level needed for a domestic firm to enjoy profitable exports.

Data limitations do not allow Melitz's predictions to be tested directly. In particular, it is practically impossible to partition firms' profits between their domestically generated portion and the part coming from exports. Our main contribution in this paper is that we are able to quantify the relationship between firm productivity and firm layoffs caused by trade. We do this by concentrating on the labor market and by employing reliable, novel data that allows us to directly identify *firm-level, trade-induced* unemployment. In addition,

[1]See Bernard, Redding, and Schott (2007), Egger and Kreickemeier (2007), Helpman, Melitz, and Yeaple (2004) among others.

we test and find support for important theoretical predictions regarding the direction and magnitude of the changes in the zero-profit productivity cutoff and the export productivity cutoff when a country pursues trade liberalization.

We stay close to the original Melitz framework and introduce tariffs to derive a structural labor equation where the interactions between total factor firm productivity and trade liberalization are the key determinants of the number of workers laid off due to trade. We start by deriving firm-level employment in an autarky equilibrium. Then, we determine the equilibrium number of workers in each firm when the country opens up to costly trade and exercises protection. As a final step, we consider the case of trade liberalization, which is the basis for our empirical analysis. The theoretical predictions of our structural model, derived when a country liberalizes its trade policy, are unambiguous and suggest that, all else equal: a) More productive firms will lay off less workers; b) The more a country opens up to trade, the more layoffs there will be in the firms that produce only for the domestic market; c) Firms in more protected industries will suffer less layoffs. The intuition behind these findings is also clear: Lower trade costs give a competitive edge to the more productive firms that can afford to cover the export entry cost. These firms compete for resources with the less productive domestically producing firms, which forces some of the latter to exit the market and leads to an increase in the zero profit productivity cutoff. In addition, all remaining firms that produce only for the domestic market suffer market share and sales losses, which are accompanied by layoffs.

To test the predictions of our theoretical labor equation empirically, we use US firm-level data for the period 1980-2005. We adopt the methodology from Olley and Pakes (1996) to calculate total factor firm productivity, and we employ the Petition for Trade Adjustment Assistance Dataset, maintained by the Employment and Training Administration of the U.S. Department of Labor, to identify directly the number of workers laid-off due to trade at the firm level. Overall, we find strong empirical support for the structural predictions of our model as well as for some theoretical implications from other studies. We show that, as expected, firm productivity, trade liberalization, and the interactions between them are key determinants of the magnitude of firm-level job destruction. More specifically, we find that a one-percent increase in firm's total factor productivity lowers the number of workers who are laid-off due to trade liberalization by 32%, while, on average, an additional one-percent of trade liberalization increases the number firm-level, trade-induced layoffs by 2%. In addition, we provide empirical support for the following theoretical predictions from Melitz (2003): a) Trade liberalization results in a higher zero-profit productivity cutoff and a lower export productivity cutoff for domestic firms; b) The increase in the zero-profit productivity cutoff for domestic production is larger than the absolute decrease in the export productivity cutoff.

The remainder of the paper is structured as follows: Section 2 presents the theoretical model. Section 3 presents the econometric model, data description, estimation, empirical results, and sensitivity analysis. Section 4 concludes.

2 Theoretical Setting

Our theoretical model follows Melitz (2003). Given our empirical strategy, however, we concentrate on the labor market and analyze the effects of trade and trade liberalization on the equilibrium number of workers employed by each firm.

2.1 Autarky Equilibrium

Consumption. The representative consumer's utility is derived from consumption of a continuum of goods indexed by ω, and takes a CES functional form:

$$U = \left[\int_{\omega \epsilon \Omega} q(\omega)^{\rho} d\omega \right]^{\frac{1}{\rho}},$$

where $q(\omega)$ is the amount of variety ω consumed, Ω is the mass of potentially available goods, and $\sigma = 1/(1-\rho) > 1$ is the elasticity of substitution between different varieties. Consumer's utility can be considered as an aggregate good, $Q \equiv U$, which is composed of different goods varieties, with a corresponding aggregate price index $P = \left[\int_{\omega \epsilon \Omega} p(\omega)^{1-\sigma} d\omega \right]^{\frac{1}{1-\sigma}}$. Making use of the definitions of aggregate consumption and the CES price index, we solve the representative consumer's problem to derive demand, $q(\omega)$, and expenditure, $r(\omega)$, for each individual variety:

$$q(\omega) = Q\left[\frac{p(\omega)}{P}\right]^{-\sigma}, \quad r(\omega) = R\left[\frac{p(\omega)}{P}\right]^{1-\sigma}, \tag{2.1}$$

where $R = PQ = \int_{\omega\epsilon\Omega} r(\omega)d\omega$ denotes aggregate expenditure.

Production. There is a continuum of firms, and each of them produces a different variety ω. Production requires only labor and takes the following linear functional form: $l = f + q/\varphi$. All firms pay the same fixed cost f, but have different productivity levels $\varphi > 0$.[2] Given the demand for individual varieties, each firm maximizes its profits by choosing the price of its own variety, which can be expressed as a mark-up over marginal cost: $p(\varphi) = \frac{1}{\rho\varphi}$, where the wage rate is normalized to one. This, in combination with the definition of expenditure from (2.1), allows us to express firm revenues as:

$$r(\varphi) = R(P\rho\varphi)^{\sigma-1}, \tag{2.2}$$

which implies that the ratio of any two firms' revenues will only depend on their productivities:

$$\frac{r(\varphi_i)}{r(\varphi_j)} = \left(\frac{\varphi_i}{\varphi_j}\right)^{\sigma-1} \tag{2.3}$$

Furthermore, firm profits and labor demand can also be expressed as functions of productivity:

$$\pi(\varphi) = \frac{r(\varphi)}{\sigma} - f \tag{2.4}$$

$$l(\varphi) = f + \frac{\sigma-1}{\sigma}r(\varphi). \tag{2.5}$$

Entry. There is a large pool of potential entrants into any industry, and prior to entry all the firms are identical. To be able to produce, firms must pay a fixed entry cost $f_e > 0$, which is

[2] Thus, each variety ω can be uniquely mapped to a single productivity level φ.

sunk. After entry, firms draw their productivity φ from a distribution $g(\varphi)$ with a cumulative distribution $G(\varphi)$. If a firm has a low productivity draw upon entry, it may decide to exit immediately and not produce. Firms that decide to produce face an exogenous probability of death δ in each period. Since the productivity level of a firm does not change throughout its lifetime, its optimal per period profit level remains constant. A firm that enters the market with productivity level φ would then immediately exit if its per period profits were negative. This scenario implies a zero profit productivity cutoff condition $\pi(\varphi^a) = 0 \iff r(\varphi^a) = \sigma f$, which determines the lowest productivity draw, φ^a, needed for a firm to stay in the market: Any firm with productivity level $\varphi < \varphi^a$ will immediately exit. The productivity distribution of the firms that stay in the market will thus be $\mu(\varphi) = \frac{g(\varphi)}{1-G(\varphi^a)}$, where $1 - G(\varphi^a)$ is the ex-ante probability of successful entry. This defines the aggregate productivity level $\tilde{\varphi}$ as a function of the cut-off level φ^a:

$$\tilde{\varphi}(\varphi^a) = \left[\frac{1}{1-G(\varphi^a)} \int_{\varphi^a}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi\right]^{\frac{1}{\sigma-1}} \tag{2.6}$$

As shown in Melitz (2003), $\tilde{\varphi}$ is also the average productivity level for the firms that choose to produce and stay in the market. The combination of equations (2.4), (2.5), and the zero profit productivity cutoff condition, makes it possible to express average revenues as a function of φ^a:

$$r(\tilde{\varphi}) = \left[\frac{\tilde{\varphi}(\varphi^a)}{\varphi^a}\right]^{\sigma-1} \sigma f. \tag{2.7}$$

Free entry implies that new firms will enter the market as long as the average profit in the industry is positive. Let M denote the equilibrium number of firms, which ensures that economic profits are competed away. [3] In equilibrium, aggregate variables such as the CES price index P and aggregate expenditure R can be expressed in terms of the equilibrium

[3]See Melitz (2003) for the properties of the equilibrium and details on aggregation.

number of firms and the average productivity:

$$P = M^{\frac{1}{1-\sigma}} p(\tilde{\varphi}) = M^{\frac{1}{1-\sigma}} \frac{1}{\rho\tilde{\varphi}} \tag{2.8}$$

$$R = M r(\tilde{\varphi}) \tag{2.9}$$

Equations (2.7), (2.8), and (2.9) allow us to express firm revenues in autarky, previously defined by equation (2.2), as a function of the zero profit productivity cutoff:

$$r(\varphi) = \sigma f \varphi^{\sigma-1} \left(\frac{1}{\varphi^a}\right)^{\sigma-1}, \tag{2.10}$$

which, in combination with equation (2.5), implies that the equilibrium number of workers employed by firm with productivity φ in autarky will be:

$$l_a = f + (\sigma-1) f \varphi^{\sigma-1} \left(\frac{1}{\varphi^a}\right)^{\sigma-1}. \tag{2.11}$$

Equation (2.11) implies that firms with higher productivity will employ more workers. The intuition behind this result is that the more productive firms will enjoy larger market shares and, therefore, will employ more workers in order to satisfy demand.

2.2 Equilibrium under Trade and Protectionism

In this section, we derive the equilibrium number of workers employed in each domestic firm after the domestic economy is opened to trade. The world consists of $n + 1 \geq 2$ identical countries.[4] Domestic firms can export their products to any country only after they pay a fixed export cost, $f_x > 0$, in addition to the fixed cost, f, which they have to incur to produce domestically. Decisions whether to export are made after each firm draws its productivity level. Regardless of their export status, all domestic firms still incur the same overhead production cost. In addition, exporting firms face higher marginal cost of their exports due

[4] This implies that each country has $n \geq 1$ potential trading partners, and all countries share the same wages and same aggregate variables. In the empirical analysis we relax the assumption that the wages are identical.

to ad-valorem tariffs, which are assumed to be symmetric across all trading partners. Thus, each firm's domestic pricing rule is given as before: $p_d(\varphi) = 1/\rho\varphi$, while the export price is: $p_x(\varphi) = (1+t)p_d(\varphi) = (1+t)/\rho\varphi$, where subscript d stands for 'domestic,' and subscript x stands for 'export.' Such price rule separability, combined with the assumption that each firm that exports must also engage in domestic production, implies separability of exporting firms' revenues:

$$r(\varphi) = \begin{cases} r_d(\varphi) & \text{if the firm does not export} \\ r_d(\varphi) + nr_x(\varphi) = [1 + (n(1+t))^{1-\sigma}]r_d(\varphi) & \text{if the firm exports to all countries.} \end{cases} \tag{2.12}$$

In addition, this allows us to decompose each exporting firm's profits into their domestic and foreign portions, $\pi(\varphi) = \pi_d(\varphi) + n\pi_x(\varphi)$, where:

$$\pi_d(\varphi) = \frac{r_d(\varphi)}{\sigma} - f, \quad \pi_x(\varphi) = \frac{r_x(\varphi)}{\sigma} - f_x. \tag{2.13}$$

Each exporting firm's labor demand can also be decomposed into its domestic and exporting portions, $l^{ct}(\varphi) = l^{ct}_d(\varphi) + nl^{ct}_x(\varphi)$, where superscript ct denotes 'costly trade' and:

$$l^{ct}_d = f + r_d(\varphi)\frac{\sigma - 1}{\sigma}, \quad l^{ct}_x = f_x + r_x(\varphi)\frac{\sigma - 1}{\sigma}. \tag{2.14}$$

As in the autarky equilibrium, there is a large pool of potential entrants and each firm that enters the market with a productivity level φ would exit immediately if its domestic profits were negative. In addition, however, some firms will also choose to export as long as their productivity draw allows them to realize non-negative profits from exports. This scenario implies two zero-profit productivity cutoff conditions: one for domestic profits, $\pi_d(\varphi^{ct}) = 0$, which determines the lowest productivity draw, φ^{ct}, needed for a firm to stay in business; and one for export profits, $\pi_x(\varphi^{ct}_x) = 0$, which determines the lowest productivity draw, φ^{ct}_x, needed for a firm to export.

The fact that each firm has to incur additional fixed costs, f_x, in order to export implies that the lowest productivity draw, φ^{ct}_x, needed for profitable exports is necessarily higher than the lowest productivity threshold, φ^{ct}, needed for domestic production. It is also important to establish the relationship between the zero-profit productivity cutoff in autarky and the two zero-profit productivity cutoffs in the trade equilibrium. As shown in Figure 1, the lowest productivity draw needed for domestic production must be higher once the country opens up to trade. This result is driven by the fact that some domestic firms find

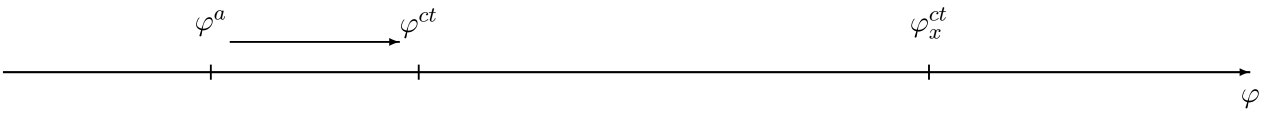

Figure 1: Firm Productivity and Costly Trade

it profitable to start exporting, which leads to an increase in their demand for resources. This forces some of the least productive domestic firms out of the market and results in an increase in the average productivity level at home, as well as to an increase in the zero-profit productivity cutoff for domestic production.

Similar to the closed economy case, but this time using the average domestic productivity level $\tilde{\varphi}$ and the average export productivity level $\tilde{\varphi}_x$, [5] we first express average revenues and all aggregates in terms of the zero-profit productivity cutoffs, and then use them to solve for the equilibrium number of workers employed in each firm depending on its export status. The labor equation for the firms that only serve the domestic market is very similar to the one describing the autarky equilibrium, the only difference being the zero domestic profit productivity threshold, φ^{ct}, which is higher in the trade equilibrium:

$$l^{ct} = f + (\sigma - 1) f \varphi^{\sigma-1} \left(\frac{1}{\varphi^{ct}}\right)^{\sigma-1}. \tag{2.15}$$

The equilibrium number of workers employed by an exporting firm is:

$$l^{ct} = f + n f_x + (\sigma - 1) f \varphi^{\sigma-1} \left(\frac{1}{\varphi^{ct}}\right)^{\sigma-1} [1 + n(1+t)]^{1-\sigma}. \tag{2.16}$$

[5] Average export productivity is similar to its domestic counterpart, and is equal to $\tilde{\varphi}(\varphi_x^{ct}) = \left[\frac{1}{1-G(\varphi_x^{ct})} \int_{\varphi_x^{ct}}^{\infty} \varphi^{\sigma-1} g(\varphi) d\varphi\right]^{\frac{1}{\sigma-1}}$.

The intuition for the effects of opening up to trade on the equilibrium firm-level employment described in equations (2.15) and (2.16) is clear: Once a country opens up to trade, the firms that export gain market share due to the fact that they are now producing for other countries as well. The increase in market share for the exporting firms is associated with more hires and increase in employment. On the other hand, some of the firms that produce only for the domestic economy are forced out of the market while others incur losses associated with layoffs. Given that the change in market share depends on the firm's export status, and hence on the productivity level of the firm, the number of laid off workers and the number of new hires will be contingent on firm productivity as well.

Taking the difference between the equilibrium number of workers employed in a domestically producing firm in the trade equilibrium, defined in equation (2.15), and the equilibrium number of workers employed by the same firm in autarky, defined by equation (2.11), gives an expression for the firm-level layoffs caused by trade. Similarly, the difference between the equilibrium number of workers employed by an exporting firm, defined in equation (2.16), and the equilibrium number of workers employed by the same firm in autarky, defined by equation (2.11), defines the number of hires due to trade.[6]

Ideally, one would like to be able to estimate both of the above relationships describing firm-level job destruction and firm-level job creation caused by trade. Empirically this is not possible for two reasons: First, in reality, we very rarely observe regime switching from autarky to trade. What we observe most of the time is trade liberalization. Therefore, in the next section, we derive and discuss the effects of trade liberalization on the labor market, which we then quantify in our empirical analysis. Second, data availability allows us to measure only firm-level layoffs caused by trade as opposed to both trade-induced layoffs and trade-induced hires. To address this issue, we resort to the properties of our theoretical setting: We employ the two-zero profit cutoff conditions to express the zero-profit domestic

[6]Technically, the exporting firms should also layoff some workers who are employed in production for the domestic market. As shown in Bernard *et al.* (2007), however, the net effect on employment in the exporting firms will be job creation, while the net effect on employment in the firms that produce only domestically will be job destruction.

productivity cutoff φ^{ct} in terms of the export productivity cutoff φ_x^{ct} and tariffs:

$$\varphi^{ct} = \varphi_x^{ct} \frac{1}{(1+t^{ct})} \left(\frac{f}{f_x}\right)^{\frac{1}{\sigma-1}}. \tag{2.17}$$

which, allows us to derive a structural equation for the number of workers employed in a domestically producing firm as a function of the zero profit export productivity cutoff and ad-valorem tariffs:[7]

$$l^{ct} \quad = \quad f + (\sigma - 1) f_x \varphi^{\sigma-1} \left(\frac{1+t^{ct}}{\varphi_x^{ct}}\right)^{\sigma-1}. \tag{2.18}$$

As will become clear in the next section, equation (2.18) allows us to quantify the relationship between trade liberalization, firm productivity, and trade-induced layoffs by just concentrating on the change in firm-level employment in the domestically producing firms.

2.3 Trade Liberalization

In this section, we examine the impact of trade liberalization, in the form of a discrete tariff reduction from t^{ct} to t^{tl}, on productivity and employment levels for domestic firms.[8] Qualitatively, the effects of trade liberalization are identical to the effects of opening up the economy to trade, described in the previous section. Figure 2 depicts the changes in the zero- profit productivity cutoffs (both domestic and export) in response to trade liberalization. The export productivity cutoff decreases from φ_x^{ct} to φ_x^{tl} because, due to lower export costs, firms with lower productivity levels now find it profitable to export, which lowers the minimum productivity threshold required for exporting. Similarly, more foreign firms enter the home market, which forces some of the least productive firms to exit

[7]For simplicity and clarity of exposition, we only consider layoffs in the domestically producing firms. As noted earlier however, equation (2.18) also describes employment of workers who are engaged in production for the domestic market in exporting firms. Empirically, this is not a problem since we observe trade-induced layoffs in all firms, regardless of their export status.

[8]It should be noted that trade liberalization is symmetric, so that any decrease in domestic protection is matched by an equivalent decrease in foreign protection, with symmetric effects on foreign firms.

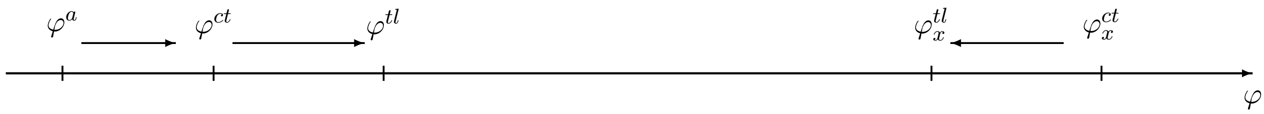

Figure 2: Firm Productivity and Trade Liberalization

and leads to an increase in the minimum threshold needed for domestic production from φ^{ct} to φ^{tl}.

As discussed earlier, the nature of available data forces us to concentrate on the labor demand for the firms that produce only domestically. In the previous section, we derived a structural equation (equation (2.16)) for the equilibrium number of workers employed by a domestically producing firm as a function of tariffs. It is possible to show that the equilibrium level of employment for domestic firms after trade liberalization is:

$$l^{tl} = f + (\sigma - 1) f_x \varphi^{\sigma-1} \left(\frac{1 + t^{tl}}{\varphi_x^{tl}} \right)^{\sigma-1}. \tag{2.19}$$

The difference between the number of workers employed by each domestically producing firm before trade liberalization (equation 2.18) and the number of workers employed by the same firm after trade liberalization (equation 2.19) defines the number of firm-level layoffs caused by trade liberalization:

$$l^{ct} - l^{tl} = (\sigma - 1) f_x \varphi^{\sigma-1} \left[\left(\frac{1 + t^{ct}}{\varphi_x^{ct}} \right)^{\sigma-1} - \left(\frac{1 + t^{tl}}{\varphi_x^{tl}} \right)^{\sigma-1} \right] > 0. \tag{2.20}$$

The assumption of trade liberalization, captured by decrease in tariffs, implies that the expression on right-hand side of equation (2.20) is strictly positive. Our final step is to make equation (2.20) econometrically operational by setting the elasticity of substitution to be equal to two, which implies:[9]

$$l^{ct} - l^{tl} = f_x \left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}} \right] \varphi + \frac{f_x}{\varphi_x^{ct}} \varphi \left(t^{ct} - t^{tl} \right) + f_x \left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}} \right] \varphi \, t^{tl} \tag{2.21}$$

equation (2.21) allows us to estimate the relation between firm-level trade-induced layoffs, firm-level productivity, and trade liberalization through the coefficients in front of φ, $\varphi(t^{ct} - t^{tl})$ and φt^{tl}. Our expectations about the signs of these coefficients are clear: The expression in brackets in the first term is negative, since the productivity cut-off level for exporting increases with trade liberalization. This suggests that, all else equal, more productive firms that only produce for the domestic market will lay off less workers. Trade liberalization is associated with more layoffs for the firms that only produce domestically. Thus, we expect the second coefficient to be positive. Finally, the negative sign of the third term implies that, all else equal, firms operating in the more protected industries will suffer less unemployment.

We finish this section by further formalizing the relationship between the zero domestic productivity cutoff and the export productivity cutoff in the following proposition:

Proposition 2.1 *With symmetric trade liberalization, the increase in the zero-profit domestic productivity cutoff is smaller, in absolute value, than the decrease in the export productivity cutoff:*

$$\left| \frac{\varphi^{ct} - \varphi^{tl}}{\varphi^{ct}} \right| < \frac{\varphi_x^{ct} - \varphi_x^{tl}}{\varphi_x^{ct}}.$$

The more a country liberalizes its trade policy, the bigger the difference between the changes in productivity cutoffs.

Proof. Apply the relationship in equation (2.17) to trade liberalization to show that:

$$\left| \frac{\varphi^{ct} - \varphi^{tl}}{\varphi^{ct}} \right| = \frac{\varphi_x^{ct} - \varphi_x^{tl} \frac{1+t^{ct}}{1+t^{tl}}}{\varphi_x^{ct}} \tag{2.22}$$

[9]We experiment with alternative plausible values for the elasticity of substitution in Appendix A. Our main empirical results do not change, and are available upon request. In addition, in our empirical analysis, we also allow for the elasticity of substitution to vary across industries, which further reinforces our main findings.

Trade liberalization, measured by reduction in tariffs, implies $\frac{1+t^{ct}}{1+t^{tl}} > 1$, which means that $\varphi_x^{tl}\frac{1+t^{ct}}{1+t^{tl}} > \varphi_x^{tl}$ and, therefore, $\frac{\varphi_x^{ct}-\varphi_x^{tl}\frac{1+t^{ct}}{1+t^{tl}}}{\varphi_x^{ct}} = \left|\frac{\varphi^{ct}-\varphi^{tl}}{\varphi^{ct}}\right| < \frac{\varphi_x^{ct}-\varphi_x^{tl}}{\varphi_x^{ct}}$.

Intuitionally, the lower magnitude if the increase in the zero-profit productivity cut-off can be explained with the secondary nature of the effect on the firms that produce only domestically. The direct effect of trade liberalization falls on the exporting side of the market where more firms can afford to bear the sunk cost of exporting and, therefore, the zero-profit export cut-off falls as a direct result of trade liberalization. The increase in the zero-profit cut-off for the domestically producing firms is caused by the fact that resource prices are bid up by the exporters and that forces some of the less productive firms to leave the market.

3 Empirical Analysis

We start this section by specifying the estimation equation and describing the data employed in our analysis. Next, we present and interpret our results to provide empirical support for the theoretical predictions derived in the previous section. Sensitivity checks confirm the robustness of our results.

3.1 Estimation Approach

To quantify the relationship between firm productivity, trade, trade liberalization, and firm-level job destruction, we translate the structural labor equation for firm i operating in industry j, $i \in j$:

$$l_i^{ct} - l_i^{tl} = f_x\left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}}\right]\varphi_i + \frac{f_x}{\varphi_x^{ct}}\,\varphi_i\,(t_j^{ct} - t_j^{tl}) + f_x\left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}}\right]\varphi_i\,t_j^{tl}, \tag{3.1}$$

into the following estimation equation:

$$UNEMPL_i = \alpha_0 + \alpha_1 TFP_i + \alpha_2 LIB_j * TFP_i + \alpha_3 T_j * TFP_i + \varepsilon_{ij}, \tag{3.2}$$

where $UNEMPL_i = ln(l_i^{ct} - l_i^{tl})$ is the logarithm of the number of workers who were laid off from firm i due to import competition, $TFP_i = \varphi_i$ is the logarithm of total factor productivity of firm i, T_j is the ad-valorem tariff faced by the international competitors of import-competing firm i operating in industry j, LIB_j is the difference between the lagged and current ad-valorem tariffs in industry j, which is a proxy for the magnitude of liberalization, and $\alpha_1 = f_x \left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}}\right]$, $\alpha_2 = \frac{f_x}{\varphi_x^{ct}}$, and $\alpha_3 = f_x \left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}}\right]$. Since f_x and each of the export productivity thresholds are positive, and the export productivity threshold decreases with trade liberalization, we form the following expectations about the estimates of the coefficients in equation (3.2): The coefficient in front of TFP_i, α_1, should be negative implying an inverse relationship between total factor productivity and the number of workers laid-off by each import-competing firm due to trade. The estimate of α_2 should be positive, implying a positive relationship between the interaction of liberalization and productivity ($LIB_j * TFP_i$): all else equal, the more open the country is, the more layoffs there will be in the domestically producing firms. Finally, theory predicts a negative sign of the coefficient on the interaction between tariffs and TFP, α_3, which implies that, all else equal, domestically producing firms in the more protected industries will lay off less workers.

The fact that we are investigating the effect of trade liberalization on unemployment only for the firms that suffer from trade implies that our results are subject to selection bias due to the fact that the firms in our sample are selected in a non-random manner. To address this problem, we follow Heckman (1979) and set up the following econometric model:

$$UNEMPL_i = \alpha_0 + \alpha_1 TFP_i + \alpha_2 LIB_j * TFP_i + \alpha_3 T_j * TFP_i + \varepsilon_{1ij} \quad (3.3)$$

and unemployment is observed if:

$$\beta_0 + \beta_1 EXCL_i + \beta \mathbf{X_{ij}} + \varepsilon_{2ij} > 0, \quad (3.4)$$

where ε_{1ij} and ε_{2ij} are correlated and normally distributed. Equation (3.4) is our selection equation based on whether a firm suffers from trade or not, ($EXCL_i$) as our exclusionary variable, and $\mathbf{X_{ij}}$ is a set of control variables, which will be described below.

Because selection is heavily present in our model, finding a good exclusionary variable is crucial for sound econometric results. Fortunately, a closer look into the Petition for Trade Adjustment Assistance data, which we use to measure firm-level trade-induced unemployment, gave us an excellent opportunity to construct a good exclusion variable. In order to get TAA, US firms have to go through a formal process of certification, where the government determines whether the firm is really affected by trade or it suffers for any other reason. One would expect that if two firms produce identical products and one of them has been TAA-certified, the other will also be eligible to enter the program. Surprisingly this is not the case, there were cases in the data when even branches of the same company, producing identical products but operating in different states, had different outcomes when applying for TAA. This made us think that overall political affiliation of a given state might be a good indicator of what firm's chances of getting TAA were. At the same time, whether a state is blue or red should not be related to any firm's performance and trade-induced unemployment, in particular. Thus, we identified the political belonging of the state for each firm in our sample and used it as an exclusionary variable in our selection model.

3.2 Data Description

An advantage of our data is that it allows us to identify directly the *trade-induced* losses, in terms of layoffs, at the firm level. We use the Petition for Trade Adjustment Assistance Database (PTAA), a data set constructed and maintained by the Employment and Training Administration of the U.S. Department of Labor, to construct our trade-induced unemployment variable. The PTAA data consists of firm-level data series at the 4-digit Standard Industrial Classification (SIC) level including the date when a petition for TAA was filed, when and whether the petition was certified, and the estimated number of workers to be laid off by each firm as a consequence of increase in the quantity of imports for the industry. We construct trade-induced unemployment by first dropping all firms whose petitions were not certified for TAA, and then summing the total number of workers who were laid off due to trade, and therefore TAA certified, for each firm and year. After that, to calculate labor costs, we follow Keller and Yeaple (2007), and multiply the number of employees in each firm (data item 29 in Compustat) by the average industry wage, which is from the Annual Survey of Manufactures (ASM) for the corresponding year.

To calculate total factor firm productivity, the main explanatory variable in our estimations, we follow the procedure described in Keller and Yeaple (2007), who adopt the methodology from Olley and Pakes (1996).[10] The latter emphasizes the simultaneity problem and selection bias for the calculation of productivity and allows for inter-industry TFP comparisons. Once we calculate total factor productivity for each firm, we merge these data with the certified firms from the TAA data set, which determines the size of the estimation sample for our main analysis to be 1738 observations.

In addition to firm-level data on layoffs and productivity, we also employ various trade variables at the industry level, including imports, exports, and tariffs. We use tariff data to test our theoretical predictions about trade liberalization. Even though non-tariff trade barriers (NTB's) are probably a more significant and relevant measure of protection, we use tariffs for two reasons: First, comprehensive data on NTB's for the period of investigation are not available. Second, we believe that U.S. tariffs, which, for the period of interest in this paper, are determined under the regulations and rules of the General Agreement on Tariffs and Trade (GATT) and the World Trade Organization (WTO), are the more appropriate measure of protection in the current theoretical setting, which assumes symmetric trade costs and symmetric trade liberalization. Therefore, we employ the change in tariffs to measure trade liberalization.[11] We use two sources for data on tariffs. Import-weighted average tariffs for the period 1980-1988 are from Bernard *et al.* (2006) and the tariffs for the years after 1989 are from Trade Analysis Information System (TRAINS).[12]

[10]See Appendix A for details on the TFP calculation procedure.

[11]In order to keep our sample size as large as possible, we use tariffs at the 3-digit SIC level to obtain our main estimation results. In the sensitivity analysis, we also experiment with tariffs at the 4-digit SIC level and obtain very similar estimates.

[12]We accessed TRAINS through the World Bank's World Integrated Trade Solution (WITS) software at

Data on sectoral imports and exports classified according to the 4-digit SIC 1972-basis are also from two sources. Data on imports up to 1989 are from Feenstra (1996) and data on exports up to 1990 are from Feenstra (1997). Trade flows for the years after 1990 (1989 for imports) are from the United Nations Conference on Trade and Development (UNCTAD) and TRAINS.

3.3 Empirical Findings and Quantitative Implications

Results from the estimation of alternative specifications of equation (3.2) are presented in Table 1. Column 1 of the table reports estimation results obtained from regressing trade-induced, firm-level unemployment on firm-level total factor productivity only. As can be seen from the table, there is a negative and significant relationship between TFP and trade-induced firm-level layoffs. Or preliminary results suggest that a 1% increase in productivity will lower trade-induced layoffs by about 14%.

Next, we estimate the full structural equation (3.2). Results, reported in column 2 are as expected: The negative and significant coefficient on TFP indicates an inverse relationship between total firm productivity and trade-induced firm level job destruction, which is in accordance with theory. It should be noted that we cannot interpret the coefficient on TFP directly as the effect of productivity on layoffs since TFP enters interactively also in the other terms in our model. We decompose and analyze the TFP effect below. We also establish a positive and significant relationship between the degree of trade liberalization interacted with TFP, and trade-induced unemployment. As expected, the positive coefficient on LIB implies that, all else equal, the more a country opens up to trade the more layoffs there will be in the import competing industries and firms. Finally, we do not find support for the prediction that, all else equal, more protected industries will layoff less workers. This can be seen from the not significant coefficient on T*TFP.

Our theoretical setting assumes that wages are equal across different firms. However, that is not the case in reality. Therefore, we control for different wages by include labor

http://wits.worldbank.org/witsweb/.

Table 1: Firm Productivity and Trade Liberalization

	(1) TFP	(2) Model	(3) Labor	(4) Sigma	(5) Polit	(6) Selection
TFP	-0.140	-0.147	-0.185	-0.183	-0.181	-0.352
	(0.074)+	(0.070)*	(0.094)*	(0.075)*	(0.081)*	(0.094)**
LIB*TFP		1.781	1.924	1.968	1.903	1.230
		(0.857)*	(0.796)*	(0.653)**	(0.872)*	(0.595)*
T*TFP		0.002	0.325	0.327	0.278	0.749
		(0.517)	(0.485)	(0.608)	(0.492)	(0.500)
LABOR_COST			0.0002	0.0002	0.0002	0.0002
			(0.000)**	(0.000)**	(0.000)**	(0.000)**
SIGMA				0.046	0.049	0.160
				(0.021)*	(0.021)*	(0.031)**
POLIT					0.167	
					(0.120)	
Constant	4.688	4.682	4.578	4.329	4.253	5.525
	(0.211)**	(0.194)**	(0.264)**	(0.220)**	(0.244)**	(0.332)**
SELECTION						
POLIT						0.099
						(0.041)*
TFP						0.112
						(0.042)**
CH NET TRADE						-0.0002
						(0.000)*
LABOR_COST						-0.000
						(0.000)
SIGMA						-0.066
						(0.012)**
Constant						0.211
						(0.146)
χ^2						71.295
λ						-2.120
						(0.093)
TFP		-.138	-.166	-.163	-.163	-.323
		(.066)*	(.089) +	(.069)*	(.078)*	(.113)**
Observations	1150	1150	1150	1025	1025	1738

Standard errors in parentheses

+ $p < 0.10$, * $p < .05$, ** $p < .01$

costs as a regressor in our empirical model. We calculate labor costs as the product of the number of employees in each firm (from Compustat) and the average industry wage (from the Annual Survey of Manufactures) for the corresponding year. Column 3 of Table 1 reports our results. Once again, we establish a negative and significant relationship between firm productivity and trade-induced layoffs. The coefficient on the interaction between productivity and trade liberalization is also significant and has the expected, positive sign. Once again, the relationship between current tariffs and layoffs due to trade is not significant. Finally, as expected, labor costs have a positive and significant effect on firm layoffs, which should not be surprising with downward-sloping labor demand: The more costly labor is, the more workers are laid off.

Another simplification in our theoretical model is the assumption of constant elasticity of substitution across sectors and varieties. While convenient, such simplification deprives the model of investigating the relationship between an important source of industry variation, such as the elasticity of substitution, and trade-induced layoffs. Therefore, our next step is to control for the variation of σ across sectors by adding in as a covariate in our estimation model. Data on the elasticities of substitution comes from Broda and Weinstein (2006). Column 4 of Table 1 presents our results, which are very similar to the ones obtained after controlling for labor costs. As expected, the new variable, SIGMA, is significant. The positive sign on the coefficient on the elasticity variable is also expected and implies that, all else equal, firms in sectors with higher elasticity of substitution will suffer more layoffs.

Next, we estimate the selection model (3.3)-(3.4), which we consider to be our best and most comprehensive specification. In order to do so, we construct an exclusionary variable, POLIT, which takes a value of one if a state is classified as republican, based on the presidential votes casted during a given election year. First, we check whether our exclusionary variable has any explanatory power in the structural equation 3.3. As can be seen from column 5, we find no relation between the political affiliation of a state and the number of workers laid off due to trade from a firm operating in this state. In addition, the signs, the significance, and the magnitude of the other explanatory variables do not change. Overall, these results suggest that POLIT might be a good exclusionary variable for our selection model.

We employ Maximum Likelihood Estimation (MLE) and the Heckman selection model (3.3)-(3.4) to obtain our main estimates reported in the last column of Table 1.[13] In addition to our exclusionary variable POLIT, we use other covariates in the selection equation, which we believe may affect TAA certification, including: firm productivity, change in net trade (increase in exports minus increase in imports), labor cost, and elasticity of substitution. As can be seen from the results presented in column 6, the coefficient on POLIT is significant, which, in combination with a Wald test ($\chi_1^2 = 71.295$) reported at the bottom of column 6, validates our selection model. The positive sign of the coefficient on POLIT implies that, all else equal, it is more likely to become TAA-certified in a republican state.[14] The positive sign of TFP in our selection equation suggests that more productive firms are more likely to get TAA. The fact that the change in net trade has negative effect on the likelihood of qualifying for TAA should not be surprising since 'increase in imports' is one of the key criteria used in the TAA certification process. Finally, we find that firms that have higher elasticity of substitution are less likely to become TAA-certified. Estimation results obtained for the structural equation after controlling for selection are qualitatively similar to the results presented in column 2: The coefficient on TFP is negative and significant; the coefficient on the interaction between trade liberalization and TFP is positive and significant; finally, the coefficient on T*TFP is still not significant. The main difference is in the magnitude on the TFP coefficient, which is now twice larger, and in the increase in the significance of TFP. These results indicate an upward bias in the effect of productivity on layoffs when selection is not controlled for.

Our estimates allow us to quantify the net effect of productivity on trade-induced layoffs.

[13]We also experiment with clustered errors to control for industry-year effects and with a jacknife procedure to correct for outliers. In each case, our results, available upon request, are very similar to the main estimates in Table 1.

[14]This, by itself, is a very interesting finding, which we investigate more thoroughly in a separate paper.

To do so, we use average tariffs and average lagged tariffs and calculate:

$$\frac{\partial UNEMPL}{\partial \overline{TFP}} = \alpha_1 + \alpha_2 \overline{LIB} + \alpha_3 \overline{T} \tag{3.5}$$

Employing the coefficients from column 6 of Table 1, which we believe are the most correctly specified, we calculate the effect of productivity on trade-induced layoffs to be negative, significant, and equal to -0.32 (standard error 0.113). This means that, all else equal, a one percent increase in the level of total factor firm productivity will lower the number of workers who are laid off by each firm because of trade liberalization by 32 percent. As can be seen from Table 1, other specifications give similar results for the negative relations between TFP and trade-induced layoffs. Our estimates of these effects, presented at the bottom of the table, range between 14 percent and 32 percent.

We are also able to quantify the effect of trade liberalization on trade-induced, firm-level layoffs. Since our trade liberalization variable enters the estimation equation in levels, while the layoffs are measured in logs, to calculate the elasticity of trade-induced layoffs with respect to trade liberalization, we multiply the coefficient in front of the interaction term LIB*TFP by the means of the TFP and LIB variables.[15] We find that a one percent increase in trade liberalization results in a significant increase of 2% (standard error 0.009) in firm-level layoffs caused by trade.

Estimation coefficients from column 6 do not allow us to recover directly the structural parameters φ_x^{ct} and φ_x^{tl}, which correspond to the productivity cutoffs for the exporting firms before and after trade liberalization. However, under the assumption that our theoretical model is a true representation of the data, we can draw some important inferences on the direction and magnitude of the changes not only in the export productivity cutoffs, but also in the domestic productivity cutoffs. The negative and significant coefficient on TFP, implies that the export productivity cutoff before trade liberalization is higher than the corresponding cutoff after trade liberalization, which is exactly what theory predicts. To see

[15] In general, in a log-linear model, the regression equation is $lnY = a + bX + \varepsilon$, and the slope coefficient is $dlnY/dX = (dY/dX)/Y$. In order to calculate the elasticity, the coefficient is multiplied by X.

this one should look at the theoretical expression of the TFP coefficient as $\alpha_1 = f_x \left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}} \right]$. Our estimate of α_1 is lower than zero, which implies that φ_x^{ct} is greater than φ_x^{tl}. Using the relation between domestic productivity cutoffs, tariffs, and export productivity cutoffs, described in equation (2.22), we show that the zero-profit productivity cutoff before trade liberalization is lower than the zero-profit productivity cutoff after trade liberalization.

Employing the coefficients on TFP and LIB*TFP from equation (3.2), we calculate and compare the percentage changes in the export and the domestic zero-profit productivity cutoffs. First, we express the decrease in export productivity cutoff, in terms of our estimated coefficients, as:

$$\frac{\varphi_x^{ct} - \varphi_x^{tl}}{\varphi_x^{ct}} = \frac{\alpha_1}{\alpha_1 - \alpha_2}. \tag{3.6}$$

Applying the Delta Method we find the above relationship to be significant, and we estimate that trade liberalisation results in a 22% (standard error 0.092) decrease in the export productivity threshold. In order to estimate the increase in the domestic zero-profit productivity cut-off, we employ equation (3.6) in combination with equation (2.22), and we use the average tariffs before and after trade liberalisation. We find the increase in the domestic zero-profit productivity cut-off to be significant and equal to 17% (standard error 0.076). The 5% difference between the changes in the export productivity and domestic productivity cut-offs is significantly different from zero at any significance level, and is in accordance with the theoretical prediction of Proposition 1.

3.4 Sensitivity Analysis

We start our sensitivity analysis by introducing some control variables, which we believe are important determinants of the magnitude of firm-level job destruction when a country liberalizes its trade policy. Potential candidates are imports and exports. The intuition for controlling for imports is clear: The more an industry is exposed to foreign competition, the more workers in this industry are likely to lose their jobs due to trade. We include exports because we expect that, all else equal, less jobs will be lost in industries with larger exports. Estimates obtained from standard OLS estimation are presented in column 1 of Table 2, while results in column 2 of the table are from a model with selection control.

Table 2: Sensitivity Analysis

	(1) No Sel-Cont	(2) Cont	(3) SIC4	(4) SIC4-Cont
TFP	-0.159	-0.327	-0.340	-0.311
	(0.077)*	(0.098)**	(0.085)**	(0.106)**
LIB*TFP	2.262	1.498	1.068	1.267
	(0.760)**	(0.717)*	(0.534)*	(0.600)*
T*TFP	0.013	0.431	0.664	0.284
	(0.548)	(0.700)	(0.447)	(0.505)
LABOR_COST	0.0002	0.0002	0.0002	0.0002
	(0.000)**	(0.000)**	(0.000)**	(0.000)**
SIGMA	0.039	0.150	0.170	0.160
	(0.020)*	(0.042)**	(0.023)**	(0.041)**
IMPORTS	0.255	0.166		0.160
	(0.042)**	(0.051)**		(0.052)**
EXPORTS	-0.383	-0.260		-0.265
	(0.090)**	(0.094)**		(0.093)**
Constant	4.248	5.460	5.498	5.457
	(0.210)**	(0.426)**	(0.276)**	(0.443)**
SELECTION				
POLIT		0.084	0.103	0.091
		(0.048)+	(0.041)*	(0.045)*
TFP		0.111	0.103	0.101
		(0.044)*	(0.042)*	(0.042)*
CH NET TRADE		-0.0001	-0.0002	-0.0001
		(0.000)+	(0.000)**	(0.000)*
LABOR_COST		-0.000	-0.000	-0.000
		(0.000)	(0.000)	(0.000)
SIGMA		-0.067	-0.070	-0.071
		(0.015)**	(0.011)**	(0.013)**
Constant		0.234	0.214	0.237
		(0.149)	(0.148)	(0.149)
χ^2		49.833	63.650	44.961
λ		-2.050	-2.113	-2.043
		(0.098)	(0.099)	(0.105)
TFP	-.147	-.307	-.315	-.297
	(0.073)*	(.091)**	(0.082)**	(0.099)**
Observations	1025	1738	1678	1678

Standard errors in parentheses

+ $p < 0.10$, * $p < .05$, ** $p < .01$

Both sets of results are very similar to our main results. We find a significant and negative impact of firm level productivity on layoffs. The coefficient on the interaction term LIB*TFP is positive and significant as expected. Once again, the coefficient on the other interaction term T*TFP, is not significant and does not have the expected sign. In line with our expectations and previous results, higher labor costs imply an increase in the trade-induced layoffs, and an increase in the elasticity of substitution is positively associated with layoffs. The positive and significant coefficient on IMPORTS implies that, all else equal, an increase in sectoral imports is associated with an increase in firm-level layoffs. Finally, the inverse relation between an increase in exports and trade-induced layoffs is captured by the negative and significant coefficient on EXPORTS.

Next, we turn to trade liberalization and tariffs. To obtain our main estimation results, we employ tariffs at the 3-digit SIC level. Here, we experiment with tariffs at the 4-digit SIC level. Arguably, 4-digit SIC tariffs are a better measure of protection for our purposes since we want to work with data at a disaggregation level which is as close as possible to the firm-level. We obtain two sets of estimation results: first using our main selection model, (column 3 of Table 2), and then after controlling for exports and imports, (column 4 of the table). Once again, both sets of results are very similar to our previous findings: The coefficients of TFP and LIB*TFP are significant and have the expected signs; but the coefficient on T*TFP still does not have the expected negative sign and is not significant; the coefficients on LABOR_COST and SIGMA are positive and significant. Finally, there is also a positive and significant relation between IMPORTS and layoffs, and a negative and significant relation between EXPORTS and layoffs.

4 Conclusion

In this paper, we attempted to fill a gap between the vast amount of theoretical literature devoted to studying the interactions between firm productivity, trade, and trade liberalization, and the lack of empirical evidence for these relationships, especially when labor markets are in question. The main contribution of our work is twofold: First, concentrating on the labor market we use reliable data, that enables us to measure directly firm-level unemployment caused by trade, and employ a selection model to quantify the relationships between productivity, trade liberalization, and trade-induced layoffs. More specifically, we find that a one-percent increase in total factor firm productivity decreases trade-induced layoffs by 32%, while an additional percent of trade liberalization increases the number of firm-level, trade-induced layoffs by 2%. Second, we provide empirical evidence for key theoretical predictions from previous studies regarding the direction and magnitude of the changes in the minimum productivity thresholds required for domestic production as well as exports. In particular, our results suggest that the zero-profit productivity cutoff for domestic firms will increase while the export productivity cutoff will fall as consequences of trade liberalization. In addition, we show that, in absolute terms, the change in the zero-profit productivity cutoff for domestic production will be larger than the change in the export productivity cutoff.

An interesting extension of this paper will be to test whether and how our findings differ for industries with comparative advantage as opposed to industries with comparative disadvantage. Bernard *et al.* (2007), extend Melitz's (2003) model by allowing for firm heterogeneity in a comparative advantage setting. They show that the zero-profit productivity cutoff increases in both types of industries but the increase is bigger in the sectors with comparative advantage. In addition, the export productivity cutoff is closer to the zero productivity cutoff in sectors with comparative advantage. In regard to the labor market, their findings suggest that trade liberalization results in simultaneous job creation and job destruction in all industries, but the comparative disadvantage industries exhibit net job destruction while comparative advantage industries experience net job creation. In accordance with their predictions, simple descriptive statistics of our data indicate that trade-induced job destruction is observed in each industry in our sample, regardless of whether the sector has a comparative advantage or not. After identifying the sectors with and without comparative advantage, our data will allow for direct testing of whether the effects of trade liberalization on the productivity cutoffs are industry-type contingent.

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Appendix A: Alternative Specification of σ

To obtain our main estimation results, we work with the simplest form of our structural labor equation by setting the elasticity of substitution to be equal to two. Here, we formally expand the polynomial defined in equation (2.18). Starting with the original equation (2.18),

$$l_i^{ct} - l_i^{tl} = (\sigma - 1) f_x \varphi_i^{\sigma-1} \left[\left(\frac{1+t^{ct}}{\varphi_x^{ct}} \right)^{\sigma-1} - \left(\frac{1+t^{tl}}{\varphi_x^{tl}} \right)^{\sigma-1} \right], \tag{4.1}$$

we can show that for reasonable values of σ, it takes the following forms:

$$l_i^{ct} - l_i^{tl} = \begin{cases} f_x \left[\frac{1}{\varphi_x^{ct}} - \frac{1}{\varphi_x^{tl}} \right] \varphi_i + \frac{f_x}{\varphi_x^{ct}} \varphi_i \, t^{ct} - \frac{f_x}{\varphi_x^{tl}} \varphi_i \, t^{tl}, & \sigma = 2 \\ f_x \left[\frac{1}{(\varphi_x^{ct})^2} - \frac{1}{(\varphi_x^{tl})^2} \right] \varphi_i^2 + \frac{f_x}{(\varphi_x^{ct})^2} \varphi_i^2 \, t^{ct} + \frac{f_x}{(\varphi_x^{ct})^2} \varphi_i^2 \, (t^{ct})^2 & \\ - \frac{f_x}{(\varphi_x^{tl})^2} \varphi_i^2 \, t^{tl} - \frac{f_x}{(\varphi_x^{tl})^2} \varphi_i^2 \, (t^{tl})^2, & \sigma = 3 \\ f_x \left[\frac{1}{(\varphi_x^{ct})^3} - \frac{1}{(\varphi_x^{tl})^3} \right] \varphi_i^3 + \frac{f_x}{(\varphi_x^{ct})^3} \varphi_i^3 \, t^{ct} + \frac{f_x}{(\varphi_x^{ct})^3} \varphi_i^3 \, (t^{ct})^2 + \frac{f_x}{(\varphi_x^{ct})^3} \varphi_i^3 \, (t^{ct})^3 & \\ - \frac{f_x}{(\varphi_x^{tl})^3} \varphi_i^3 \, t^{tl} - \frac{f_x}{(\varphi_x^{tl})^3} \varphi_i^3 \, (t^{tl})^2 - \frac{f_x}{(\varphi_x^{tl})^3} \varphi_i^3 \, (t^{tl})^3, & \sigma = 4 \\ \quad . \quad . \quad . & \sigma \in \{5, 6, 7\} \end{cases}$$

We estimate the above equations, derived for different values of σ, to find that the new estimates, available upon request, are very similar to the main results reported in Table 1 and the sensitivity analysis presented in Table 2.

Appendix B: TFP Calculation Procedure

Consider the following production function that assumes Cobb-Douglas technology:

$$y_{it} = \beta_0 + \beta_l l_{it} + \beta_m m_{it} + \beta_k k_{it} + u_{it}, \tag{4.2}$$

where y_{it} is the logarithm of the firm i's output at time t, while l_{it}, m_{it} and k_{it} represent the firm i's (logarithm of) labor, materials and capital inputs respectively. Let the error term u_{it} be composed of two parts,

$$u_{it} = \omega_{it} + \eta_{it}, \tag{4.3}$$

The simultaneity problem here is that a part of the productivity, ω_{it}, will be observed by the firm and will affect its decision of the factor inputs such as labor or materials. Hence, the error term and the regressors will be correlated and OLS estimation will give biased results.

Selection bias arises because some of the firms stop producing and exit the market in a non-randomly manner. This could be the case when firms with higher levels of capital are less likely to exit the market when there is a low realization of ω_{it}. Given that small firms might exit at productivity draws for which large firms would keep operating, the correlation between ω_{it} and k_{it} is negative. Failing to control for this self-selection will cause a negative bias in the capital coefficient. However, given our data set, we do not have firms that exit the market during the time period analyzed and hence we do not correct for this bias.

Following previous empirical work, we assume that labor and materials are variable inputs, so they are contemporaneously correlated with ω_{it}, however capital k_{it} is determined by past values of ω, not the current one. So, investment is a strictly increasing function of ω_{it} and k_{it}, and provided that $i_{it} > 0$ it can be inverted to get an expression for the productivity ω_{it}.

$$\omega_{it} = h_{it}(i_{it}, k_{it}) \tag{4.4}$$

Substituting (4.4) into (4.2) will give us:

$$y_{it} = \beta_l l_{it} + \beta_m m_{it} + \phi_{it}(i_{it}, k_{it}) + \eta_{it}, \tag{4.5}$$

where $\phi_{it}(i_{it}, k_{it}) = \beta_0 + \beta_k k_{it} + h_{it}(i_{it}, k_{it})$, and can be estimated by a forth order polynomial in k_{it} and i_{it}. So, in the first step, we estimate the equation (4.5) and get consistent estimates for β_l and β_m. Then, in order to identify β_k, we assume ω_{it} is a random walk i.e., $\xi_{it} = \omega_{it} - \omega_{it-1}$ and estimate the following equation:

$$y_{it} - \hat{\beta}_l l_{it} - \hat{\beta}_m m_{it} = \beta_k k_{it} + g(\hat{\phi}_{it-1} - \beta_k k_{it-1}) + \xi_{it} + \eta_{it}, \tag{4.6}$$

where $\hat{\phi}_{it-1}$ is estimated from (4.5), $\hat{\phi}_{it-1} - \beta_k k_{it-1}$ is an estimate of ω_{it-1} and the unknown function $g(.)$ is a fourth order polynomial in $\hat{\phi}_{it-1} - \beta_k k_{it-1}$ and $\hat{P}_{it}$. After estimating equation (4.5), we estimate the log total factor productivity as:

$$tfp_{it} = y_{it} - \hat{\beta}_l l_{it} - \hat{\beta}_m m_{it} - \hat{\beta}_k k_{it} \tag{4.7}$$

Data on firm level output, labor, materials and capital, needed to calculate firm productivity, are from the Standard & Poor's Compustat Industrial Database. Output is measured as the value of nominal net sales (data item 12 in Compustat), which we deflate by using value added price deflators from Bureau of Economic Analysis (BEA) at the 2 digit NAICS. The nominal value of expenditures on materials is calculated by subtracting capital depreciation and amortization (data item 14 in Compustat) and labor costs from the total cost of goods sold (data item 41) and selling, general, and administrative expenses (data item 189 in Compustat). We deflate the nominal material costs by the 2-digit NAICS industry material price deflators from the BEA and Bartelsman, Becker, and Gray (2001). Labor costs are calculated as the product between the number of employees in each firm (data item 29 in Compustat) and the average industry wage, which is from the Annual Survey of Manufactures (ASM) for the corresponding year. Capital, (data item 8 in Compustat), is defined as the value of property, plant and equipment net of depreciation. To deflate this variable we use the 2-digit NAICS industry investment price deflators from the BEA and Bartelsman, Becker, and Gray (2001). Finally, we use the same deflators to adjust the nominal value for investment, which also comes from Compustat.