The Impact of Trade Liberalization on Productivity Within and Across Industries: Theory and Evidence

Josh Ederington
University of Kentucky

Phillip McCalman
University of California-Santa Cruz*

February 2007

Abstract

Numerous studies have investigated the link between trade policy and firm productivity. Despite justifying firm level analysis on the basis of considerable heterogeneity between firms within narrowly defined industries, these studies typically constrain all firms to have the same expected response to changes in trade policy. In this paper we develop a theoretical model that accounts for the existence of firm level heterogeneity within industries and predicts that the equilibrium response to changes in trade policy will also be heterogeneous. The variation in firm level reaction is shown to be determined by both firm and industry characteristics and therefore the equilibrium response to trade policy is predicted to vary not only within industries but also across industries. These results allow us to use both sources of variation in the data. We examine these predictions on a firm level data set for the Colombian manufacturing sector in the 1980's and find strong support for them.

*Ederington: 335 Gatton Building, Department of Economics, University of Kentucky, Lexington, KY 40506 (email: ederington@uky.edu); McCalman: Department of Economics, University of California, 1156 High Street, Santa Cruz, CA 95064 (email: mccalman@ucsc.edu).

1 Introduction

A common question in discussions of trade reform is what impact, if any, trade policy has on firm and industry productivity. Throughout the 1960's and 1970's, many developing countries erected trade barriers in the hopes of expanding the industrial sectors of their economy. The standard rationale behind such policy was that firms would feel better able to invest in new infrastructure and advanced production techniques if guaranteed protection from foreign competition. Thus, trade barriers were seen as a necessary component in developing infant industries. This policy of economic development through protectionism has largely been supplanted by an emerging conventional wisdom that greater openness to foreign competition induces productivity gains. The idea behind the new strategy is that domestic firms will be forced to adopt new technologies and cut costs in order to compete with foreign firms. Thus, the reduction of domestic trade barriers is now seen as necessary in providing impetus for domestic firms to modernize. In this paper, we analyze, both theoretically and empirically, this link between trade policy and firm productivity.

Not surprisingly, there is a voluminous empirical literature on the question of whether the liberalization of domestic trade barriers improves firm productivity performance. However, this empirical evidence is relatively mixed. Some studies suggest that the typical firm improves its productivity performance in response to lower tariffs (see for example Krishna and Mitra (1998), Pavcnik (2002), Muendler (2004), Amiti and Konings (2005) and Fernandes (2006)). Other studies find the opposite, that a firms productivity performance is improved by tariff protection (Konings and Vandenbussche (2004)). Finally, some studies find that a reduction in domestic tariffs has no significant impact on firm level productivity (Trefler (2004)).[1] In a sense, the contradictory results of previous empirical literature are not that surprising as the mechanism through which trade actually impacts firm productivity is not formalized, and thus, there is no a priori reason to expect any particular relation.[2] One obvious means by which trade impacts firm productivity is by affecting the decisions of firms to invest in new production techniques and adopt new technologies. However, even in the theoretical technology adoption literature, the impact of trade on firm productivity is ambiguous. This is nicely demonstrated in Rodrik (1992) which shows that standard arguments for how trade barriers might impact firm productivity are misleading or incomplete.[3]

In this paper we develop a model of endogenous technology adoption by profit maximizing firms within a small, open economy. Our framework includes two key features missing from previous

[1] Also see Baggs, Head, and Ries (2002), Bustos (2006) and Conway (2006) for other studies of plant-level data and the impact of trade liberalization. Syverson (2004) also finds results that are contrary to the existing theoretical models.

[2] Indeed the relatively atheoretic approach in the empirical literature stems from the lack of any clear predictions from the theoretical literature. Tybout (2002) provides a succinct summary of the empirical view of the theoretical literature. As we note below the previous theoretical literature has concentrated almost exclusively on representative firm models, leaving no scope for any within industry heterogeneity in response to trade barriers.

[3] Also see Miyagiwa and Ohno (1995) in which the impact of trade protection on technology adoption depends crucially on the precise characteristics of the trade barriers.

models. First, our model allows for differences between firms within industries, and in contrast to other models these differences are not imposed exogenously but derived endogenously. In particular, differences between ex ante identical firms are derived as the equilibrium outcome of a technology adoption process, where diffusion arises in equilibrium (i.e. firms adopt at different dates).[4] Second, unlike previous models of technology adoption we allow the number of firms to be determined endogenously.[5] The main conclusion of our technology adoption model is that the equilibrium response to a change in trade policy is heterogeneous: both across firms and across industries.

More specifically, we find that, holding the number of domestic firms constant, a tariff has a positive impact on firm productivity (this result is due primarily to the scale effect where a tariff results in larger sales for domestic firms). However, the increased domestic profits created by a tariff induces entry by domestic firms, which reduces the incentive for each individual firm to adopt the productivity-improving innovation. Thus, the positive direct effect of trade protection is countered by a negative indirect effect. First, we show that this indirect effect is weaker at the beginning of the diffusion process and stronger at the end of the diffusion process, resulting in trade barriers having a positive impact on productivity for those firms who adopt new technologies most readily, and a negative impact on productivity for the late-adopting firms. The implication of this result is that the impact of trade policy differs across firms in the *same* industry. These differences are not just qualitative; some firms grow faster while others grow slower (i.e. the derivatives have different signs). Second, given this heterogeneity in response to a tariff, it is natural to ask what happens to the majority of firms within an industry. We show that the indirect effect is stronger in industries with certain characteristics: low entry costs, high trade barriers, large domestic markets and a small technology gap between firms. The implication of this result is that the impact of a given trade policy on firm productivity is heterogeneous *across* industries, with the behavior of a typical firm (say the median firm) within an industry conditional on the characteristics of that industry (i.e. the impact of a change in tariffs interacts with industry characteristics.). Thus, the impact on the mean firm within an industry is ambiguous, which offers insight into the mixed results of the previous literature which has focused on the average impact of reductions in trade barriers.

Finally we look for evidence of such variation in productivity when trade barriers change, by investigating the experience of Colombian manufacturing firms in the 1980's.[6] This was a period of widespread trade liberalization in Colombia, with the average tariff falling from a peak of 45 percent in 1984 to 21 percent in 1991. Moreover, the initial tariff rates and the subsequent changes in tariffs varied widely across industries, providing a rich setting for the investigation of the impact of trade policy on firm level productivity. Firm level productivity is estimated from the Colombian census of manufactures, which also provides information on a number of industry level characteristics that the theory predicts should be important for how trade policy impacts an industry. We look

[4]See Yeaple (2005) for a static model of trade and technology choice.

[5]Both Rodrik (1992) and Miyagiwa and Ohno (1995) are primarily concerned with a single import competing firm.

[6]For studies on Colombia over a similar time period see Goldberg and Pavcnik (2005), Brooks (2006) and Fernandes (2006).

for firm/industry heterogeneity in the tariff response, by including interaction terms in standard productivity growth regressions.

We find evidence of firm/industry heterogeneity that is consistent with our theoretical predictions. In particular, comparing the behavior of the median firm across industries, it is found that the direct effect of higher tariffs is to increase productivity growth of the median firm. However, the total effect includes the indirect effects of tariff changes that interact with industry characteristics. Consistent with the theoretical model, industries that have lower barriers to entry, a smaller technology gap, larger domestic markets and higher initial tariffs tend to experience lower productivity growth when tariffs increase. Furthermore, these findings are robust across a number of specifications. We also find evidence that tariff changes have a differential impact on productivity growth rates of firms within industries. Specifically, firms that would be predicted to have high productivity growth over the period investigated (the early adopters), had this growth further enhanced by an increase in tariffs. In contrast, firms that would be predicted to have low productivity growth (the late adopters), tended to have their performance further undermined by a tariff. It is worth reiterating that these results relate to firms in the same narrowly defined industry and are consistent with the theoretical model that relates the diffusion of technology to changes in trade policy. These results, together with the theoretical model, suggest that the mixed empirical findings of the previous literature arise from misspecified models, and that the relationship between productivity and trade policy is more nuanced than previously considered, both within and across industries.

Section 2 of the paper provides a closed economy model of firm decisions to adopt productivity-enhancing technologies. In Section 3 we use this model to generate predictions on how tariff changes impact firm technology decisions and hence productivity growth. Finally, in Section 4, we use the Colombian tariff experience to investigate potential heterogeneity in the marginal impact of tariff changes on productivity growth.

2 Closed Economy Model

To consider how trade barriers impact firm productivity, we must first develop a model of what determines a firms decision to invest in a productivity-enhancing technology. In this section we present such a model of endogenous technology adoption. The adoption decision of firms follows the standard setup as presented in Reinganum (1981), with the exception that this framework is integrated into a model of monopolistic competition with endogenous entry. By considering adoption in a setting of monopolistic competition we are following Götz (1999) and Ederington and McCalman (2006). However, both of these papers use CES preferences while we employ a quadratic utility function since it features a demand system with variables elasticities of demand.[7]

[7] For models that emphasizes trade and technology in a strategic setting see Bagwell and Staiger (1992), Miyagiwa and Ohno (1995) and Crowley (2006).

2.1 Preferences and Consumption Decisions

We assume that the economy has two sectors: one sector consists of a numeraire good, x_0, while the other sector is characterized by differentiated products. The following utility function defines the preferences of a representative consumer:

$$U = x_0(t) + C(t) \tag{1}$$

where $x_0(t)$ is consumption of the numeraire good in time t and $C(t)$ represents an index of consumption of the differentiated goods. We assume a quadratic specification for this consumption index which reflects a taste for variety

$$C(t) = \alpha \int_0^{n(t)} y(i,t)di - \frac{1}{2}\int_0^{n(t)} (y(i,t))^2 di - \frac{1}{2}(\int_0^{n(t)} y(i,t)di)^2$$

where $y(i,t)$ represents consumption of brand i at time t and $n(t)$ represents the number of varieties available at time t. Since the instantaneous utility is quasi-linear demand for good i at time t is:

$$y(i,t) = A(t) - p(i,t) \tag{2}$$

where $p(i,t)$ is the price of good i in time t and $A(t) = \frac{\alpha + n(t)\overline{p}(t)}{(1+n(t))}$ is the choke price and $\overline{p}(t)$ is the average price in the industry. If we treat these as individual demands, market demand follows from multiplying individual demands by population. For simplicity we normalize population size to unity.

2.2 Technology

In order to facilitate the analysis the production side of the economy is kept as simple as possible. We assume that all goods are produced using constant returns to scale technologies and a single factor of production, labor. Thus, production of any good (or brand) requires a certain amount of labor per unit of output. As is standard, we assume that production of the numeraire good is defined by $l = x_0$ which ensures that the equilibrium wage is equal to unity.

In order to produce in the differentiated goods sector we assume that firms must pay a sunk entry fee of F. Once this fee has been paid, a variety of the differentiated good can be produced using either of two types of technology. A low-productivity technology is always available to any firm upon entering the industry. The constant marginal cost of production for a low-tech firm is denoted by c. A high-productivity technology is also available at time $t = 0$, but requires an additional fee of $k(t)$ where $k(0) = \infty$, $k(\infty) = \overline{k}$, $k' < 0$ and $k'' > 0$.[8] With this adoption cost function, earlier adoption is more expensive; however, the decreasing cost of technology adoption implies that eventually all firms that remain in the industry will adopt the high-tech process. The marginal cost of production using the high-productivity technology is assumed to be zero. Therefore, c is an index of the size of the technological innovation.

[8]These are standard assumptions in the technology diffusion literature, see for example Reinganum (1981) and Fudenberg and Tirole (1985). The only difference is that we assume $k(t)$ is bounded from below to rule out the possibility of entry occurring after all the initial entrants have adopted. Note that in these papers the possibility of entry is not considered.

2.3 Prices and Profits

In this model, firms have four choices to make: when to enter, what price to charge, when to adopt the new technology, and whether (and when) to exit. Since the pricing decision is central to all of the other decisions through its impact on profits, this is where we begin our characterization of firm behavior.

The model admits heterogeneity in terms of the technology of firms. The goal is to derive these technology positions endogenously. However, to start with we assume that some fraction, q, of the firms are hi-tech. Given the linear demands and constant marginal cost, the optimal prices of firms (taking $\overline{p}$ as given) are:

$$\begin{aligned} p_L &= \frac{A+c}{2} = \frac{\alpha + n\overline{p}}{2(1+n)} + \frac{c}{2} \\ p_H &= \frac{A}{2} = \frac{\alpha + n\overline{p}}{2(1+n)} \end{aligned}$$

This implies that $p_L = \frac{c}{2} + p_H$. Note also that $\overline{p} = qp_H + (1-q)p_L$. Together these imply that $\overline{p} = p_H + (1-q)\frac{c}{2}$, substituting for p_H, we get:

$$\overline{p} = \frac{c(1-q)(1+n)+\alpha}{2+n} \tag{3}$$

This implies individual prices at any point in time are described by:

$$\begin{aligned} p_L &= \frac{c}{2} + \frac{(1-q)cn}{2(2+n)} + \frac{\alpha}{2+n} \\ p_H &= \frac{(1-q)cn}{2(2+n)} + \frac{\alpha}{2+n} \\ A &= \frac{2\alpha + cn(1-q)}{2+n} \end{aligned} \tag{4}$$

Using the optimal prices, we can derive the value functions for per period profits:

$$\pi_i = \frac{(\frac{\alpha+n\overline{p}}{1+n} - c_i)^2}{4} = \frac{(A-c_i)^2}{4}$$

Since $c_L = c$ and $c_H = 0$, hi-tech firms make larger per-period profits. Thus, the basic payoff to adopting a productivity-enhancing technology is that it results in lower marginal costs of production, and thus higher per-period profits in equilibrium. However, the pay-off to adoption is declining in q.

2.4 Technological Progress

The equilibrium distribution of technology at any point in time, $q(t)$, is determined by the firms' selection of their optimal adoption dates. Taking this distribution as given, a firm chooses the adoption date, T, to maximize the discounted value of total profits:

$$\Pi = \int_0^T e^{-rt}\pi_L(q(t))dt + \int_T^\infty e^{-rt}\pi_H(q(t))dt - K(T) - F$$

where $K(T) = e^{-rT}k(T)$. These profits depend on both the firm's own adoption date, T, and the adoption decisions of rival firms (which is summarized by the distribution function $q(t)$). Differentiating with respect to T yields the first-order condition:

$$\pi_H - \pi_L = -K' e^{rT} \tag{5}$$

The above first-order condition demonstrates the trade-off faced by firms in the choice of when to adopt. The left-hand side is the lost profits from waiting one more period to adopt the high-productivity technology while the right-hand side is the gain from the decrease in adoption costs from delaying adoption another period. Substituting the profit differential into this first-order condition gives:

$$\begin{aligned} \frac{(2A-c)c}{4} &= -K' e^{rT} \\ A &= \frac{-2K' e^{rT}}{c} + \frac{c}{2} \end{aligned} \tag{6}$$

Not surprisingly this tells us that the choke price is decreasing over time. This also tells us that when the first order conditions hold, profits (either π_L or π_H) are independent of n and α.

Returning to the evaluation of the first order condition, note in particular that it holds for all firms that have yet to adopt. However, if all such firms adopted at once this first order condition would not hold, with most firms instead preferring to adopt at other dates in the future (since adoption en masse would drive the LHS below the RHS). This implies that the first order condition doesn't just hold at one point in time but over an interval, with a firm indifferent over which date in this interval it adopts (i.e. an early adoption date confers a greater increase in profits but is associated with a higher opportunity cost, while a later date involves a lower profit differential but also a lower opportunity cost of waiting.) By combining (4) and (6), the distribution function that describes the optimal adoption dates is derived as:

$$q^*(t) = \begin{cases} 0 & \text{for } t \in [0, T_L) \\ \frac{1}{2} + \frac{(2\alpha - c)}{cn} + \frac{2(2+n)K' e^{rt}}{c^2 n} & \text{for } t \in [T_L, T_H] \\ 1 & \text{for } t \in (T_H, \infty) \end{cases}$$

The above distribution function describes the process of technological progress in the closed economy case. Given initially high adoption costs, all firms are low-tech until T_L. At T_L the first firm adopts the high-productivity technology and, as adoption costs fall, more firms adopt the new technology, leading to a gradual diffusion of the new technology through the industry for periods $T_L \leq t \leq T_H$ (where the fraction of firms that have adopted at any point in time is given by $q^*(t)$). Finally, all firms will have adopted the new technology by period T_H.

To close the model we assume entry occurs until the present value of profits are zero. These profits can be split into three periods, π_0, when all local firms are low-tech, Π_A, profits during the adoption process and π_1, profits when everyone is hi-tech. We use δ_0 and δ_1 to denote the discount factors associated with the initial and subsequent steady states. This zero profit condition implicitly defines the number of firms (varieties):[9], [10]

$$\begin{aligned}\Pi &= \delta_0\pi_0 + \int_{T_L}^{T_H} \pi_L(q)e^{-rt}dt + \delta_1\pi_1 - K(T_H) - F \\ &\Rightarrow \frac{\delta_0(A_0-c)^2}{4} + \int_{T_L}^{T_H} \frac{(A(q(t))-c)^2}{4}e^{-rt}dt + \frac{\delta_1 A_1^2}{4} - K(T_H) - F = 0\end{aligned}$$

2.5 Comparative Statics in the Closed Economy

One of the advantages of using the quadratic utility function is that it allows the elasticity of demand to be influenced by market conditions. Thus, in our model, market conditions influence the speed of technology adoption both by impacting the size of a firm and the elasticity of demand faced by that firm. An interesting comparative static in this context relates to market size. First, suppose that we increase the demand parameter, α, while holding the number of firms in the industry, n, constant. It is direct to derive from (5) that the profit differential has increased and thus, from (7), the equilibrium q has increased for any t in the diffusion phase.

However, note that an increase in market size will also induce the entry of more firms into the market. Thus, a similar issue worth examining in the closed economy setting is how a change in the number of firms impacts technology adoption decisions. For example, assume that barriers to entry, F, decrease so that more firms enter ($dn > 0$). The first order condition for adoption ensures that

[9] The zero profit condition is written for the last firm to adopt. To see that it is immaterial which adoption date we choose for the zero profit condition, consider the value function for the first and last adopters:

$$\begin{aligned}\delta_0\pi_0 + \int_{T_L}^{T_H} \pi_H(q)e^{-rt}dt + \delta_1\pi_1 - K(T_L) &= F \\ \delta_0\pi_0 + \int_{T_L}^{T_H} \pi_L(q)e^{-rt}dt + \delta_1\pi_1 - K(T_H) &= F\end{aligned}$$

The difference between these two equations is:

$$\int_{T_L}^{T_H} (\pi_H(q) - \pi_L(q))e^{-rt}dt = K(T_H) - K(T_L)$$

which must hold in equilibrium due to (5).

[10] Note that this zero profit condition also implies that there will be no exit. To see this note that the following conditions hold in equilibrium:

$$\begin{aligned}\delta_0\pi_0 + \Pi_A + \delta_1\pi_1 - K(T_H) &= F \\ \delta_0\pi_0 + \Pi_A + \delta_1\pi_1^L &< F\end{aligned}$$

where π_1^L are the variable profits from operating in an environment where all other firms are high-tech. If π_1^L=0, then firms potentially have an incentive to exit. However, if π_1^L=0, then the above equilibrium conditions imply:

$$\begin{aligned}&\delta_1\pi_1 > K(T_H) \\ &\Rightarrow F > \int_0^{T_H} \pi_L(q)e^{-rt}dt\end{aligned}$$

Consequently, no firm enters at $t = 0$ with the intention to exit, since they wouldn't be able to cover their entry cost. For a proof that all entry must occur at $t = 0$, see Ederington and McCalman (2006).

$d\Pi_A = 0$ and thus, from the zero-profit condition, one derives:

$$d\Pi = \delta_0 d\pi_0 + \delta_1 d\pi_1 - dF = 0$$

$$\begin{aligned} d\pi_0 &= dn\pi_n^0 = \frac{(A_0 - c)^2}{2(2+n)}(-dn) < 0 \\ d\pi_1 &= dn\pi_n^1 = \frac{A_1^2}{2(2\gamma+n)}(-dn) < 0 \end{aligned}$$

The decreased profits of the initial period (i.e., $d\pi_0 < 0$) translates into a delayed T_L while the decreased profits of the final period (i.e., $d\pi_1 < 0$) translates into a delayed T_H. Thus, an increase in the number of firms in the market delays the speed of technology diffusion. This result is due primarily to the scale effect, as an increase in the number of firms reduces the size of each individual firm and thus decreases the incentive to invest in cost-reducing technologies.

In conducting comparative statics, one must account for both the direct impact of a change in market conditions and the indirect impact in that changing market conditions will also affect the number of firms in the market. Thus, an increase in market size (i.e., an increase in α) will have the following impact on the zero profit condition:

$$d\Pi = \delta_0 d\pi_0 + \delta_1 d\pi_1 = 0$$

where

$$\begin{aligned} d\pi_0 = d\alpha\pi_\alpha^0 + dn\pi_n^0 &= d\alpha\left(\frac{A_0 - c}{2+n}\right) + dn\left(\frac{-(A_0-c)(\alpha-c)}{(2+n)^2}\right) \\ \Rightarrow \frac{d\pi_0}{d\alpha} &= \frac{A_0-c}{2+n}\left(1 - \frac{dn}{d\alpha}\frac{\alpha-c}{(2+n)}\right) > 0 \end{aligned}$$

$$\begin{aligned} d\pi_1 = d\alpha\pi_\alpha^1 + dn\pi_n^1 &= d\alpha\left(\frac{A_1}{2+n}\right) + dn\left(\frac{-A_1\alpha}{(2+n)^2}\right) \\ \Rightarrow \frac{d\pi_1}{d\alpha} &= \frac{A_1}{2+n}\left(1 - \frac{dn}{d\alpha}\frac{\alpha}{(2+n)}\right) < 0 \end{aligned}$$

Note that π_i is an increasing function of A_i, so changes in π_i are driven by changes in A_i. As can be seen above, an increase in α will increase profits in the initial periods and will result in initial adoption occurring earlier (i.e., T_L decreases). Alternatively, an increase in α will reduce profits in the final period and the last adoption will occur later (i.e., an increase in T_H). Thus, changes in market size have a heterogeneous impact on firm adoption decisions, speeding them up for initial adopters and delaying them for late adopters. The intuition for this heterogeneity follows directly from the change in the intensity of competition associated with technology adoption. Note that the increase in α has a positive direct impact on technology adoption, but also induces additional entry which delays technology adoption (a negative indirect effect). During the diffusion phase, as firms adopt the more advanced technology, the indirect effect has an increased impact on the adoption decisions of the marginal firm as the increase in the number of firms is complemented by an increase in technical efficiency of those same firms. Thus, while the negative indirect effect is *not* sufficient to totally offset the positive direct effect of the increase in α when all firms are low tech, it is when all firms are high-tech. Since the impact of trade is comparable to a change in market size, the heterogeneous impact of market size on firm adoption decisions suggests potential heterogeneity in the effects of trade. We explore this potential heterogeneity in the following section.

3 Technology Gaps and Trade

Having setup a benchmark model of productivity-enhancing technology adoption, we can now move on to the question of the relationship between trade policy and productivity. In this section, we analyze a central concern in the policy literature: how the presence of trade barriers impacts the productivity of firms within a small, open economy which faces a technology gap in competing with more productive foreign firms. To make the point as simply as possible, assume that the number of foreign firms is fixed and that they are all high-tech. In contrast, domestic firms are, initially, all low-tech (i.e., they face a technology gap relative to their foreign rivals that they can close by adopting the hi-tech methods). For simplicity it is assumed that domestic firms don't export.

Profit maximization gives the following domestic and foreign prices:

$$\begin{aligned} p_i &= \frac{\alpha + n\overline{p}}{2(1+n)} + \frac{c_i}{2} \\ p^* &= \frac{\alpha + n\overline{p}}{2(1+n)} + \frac{b}{2} \end{aligned}$$

where b represents the specific tariff applied by the domestic government. The average price is:

$$\begin{aligned} \overline{p} &= p_H + \frac{\theta(1-q)c}{2} + \frac{(1-\theta)b}{2} \\ \Rightarrow A &= \frac{2\alpha + n\overline{p}}{n+1} = \frac{2\alpha + cn_h(1-q) + bn_f}{2+n} \end{aligned}$$

where θ represents the fraction of firms that are domestic and $n = n_h + n_f$. The equilibrium distribution function is now given by:

$$q^*(t) = \begin{cases} 0 & \text{for } t \in [0, T_L) \\ \frac{1}{2} + \frac{(2\alpha - c)}{cn_h} + \frac{(2b-c)n_f}{2cn_h} + \frac{2(2+n)K'e^{rt}}{c^2 n_h} & \text{for } t \in [T_L, T_H] \\ 1 & \text{for } t \in (T_H, \infty) \end{cases}$$

Taking the number of domestic (n_h) and foreign (n_f) firms as given, it follows immediately that higher trade barriers increase the speed of adoption. Once again, this positive direct impact is due primarily to the scale effect as protection increases the market share of domestic firms, and thus increases their incentive to invest in productivity-enhancing technology.

However, this analysis is incomplete as it fails to account for the indirect effects of trade protection. Specifically, trade barriers tend to increase profits for domestic firms, inducing the entry of additional domestic firms into the market. Thus, in the following sections we consider the combined direct and indirect effects of an increase in trade protection on the adoption decisions of domestic firms.

3.1 Firm-level Heterogeneity in Tariff Response

To gain insight into the relative intensity of the direct and indirect effects, assume that both domestic and foreign firms are in the market, and consider a small tariff change, db, that has firms from both countries continuing to operate after the change. To work out the impact of an increase in trade barriers, we totally differentiate the zero profit condition.

$$d\Pi = \delta_0 d\pi_0 + d\Pi_A + \delta_1 d\pi_1 = 0$$

The first order conditions for adoption once again ensure that $d\Pi_A = 0$, with the implication $\delta_0 d\pi_0 = -\delta_1 d\pi_1$. This implies that the impact of a tariff on per-period profits at various times is given by:

$$\begin{aligned}
\frac{d\pi_0}{db} &= \frac{(A_0 - c)}{2(2+n)}\left(n_f - \frac{dn_h}{db}(A_0 - c)\right) \\
&= \frac{\delta_1 A_1 (A_0 - c) n_f}{2(2+n)}\left(\frac{A_1 - (A_0 - c)}{\delta_0 (A_0 - c)^2 + \delta_1 A_1^2}\right) > 0
\end{aligned}$$

$$\begin{aligned}
\frac{d\pi_1}{db} &= \frac{A_1}{2(2+n)}\left(n_f - \frac{dn_h}{db}A_1\right) \\
&= \frac{\delta_0 A_1 (A_0 - c) n_f}{2(2+n)}\left(\frac{(A_0 - c) - A_1}{\delta_0 (A_0 - c)^2 + \delta_1 A_1^2}\right) < 0
\end{aligned}$$

The increase in per-period profits in the initial periods implies that T_L decreases while the decrease in final per-period profits implies that T_H increases. Thus, the process of adoption starts earlier but takes longer in response to a tariff increase. Once again the intuition follows from the change in the intensity of competition implied by technology adoption and how this interacts with a larger number of domestic firms. While a tariff induces more firms to enter the market, this entry isn't sufficient to offset the increase in demand for domestic products generated by a tariff when all domestic firms are low tech. As these low tech firms experience an increase in demand from a tariff, they are induced to start adopting earlier. However, as the now more numerous domestic firms start adopting the superior technology, the intensity of competition increases to such an extent that the last firm to adopt has their marginal benefit from adoption lowered by the tariff. Since a tariff induces more entry, eventually this generates more high-tech domestic firms, with the impact of the greater number of high-tech domestic firms most apparent at the end of the adoption process. Consequently, our framework predicts that tariffs will have a heterogeneous impact on firms within an industry:

PROPOSITION 1 *A tariff will speed up the adoption date of early adopters and delay the adoption date of late adopters.*

That is, within industries, the model predicts that the impact of a tariff change will not be uniform across firms. Instead firms that have the apparent advantage of relatively high productivity growth see this advantage further enhanced by a tariff, while those that appear to lag the technology frontier the most will find their relative productivity growth further disadvantaged by a tariff.[11]

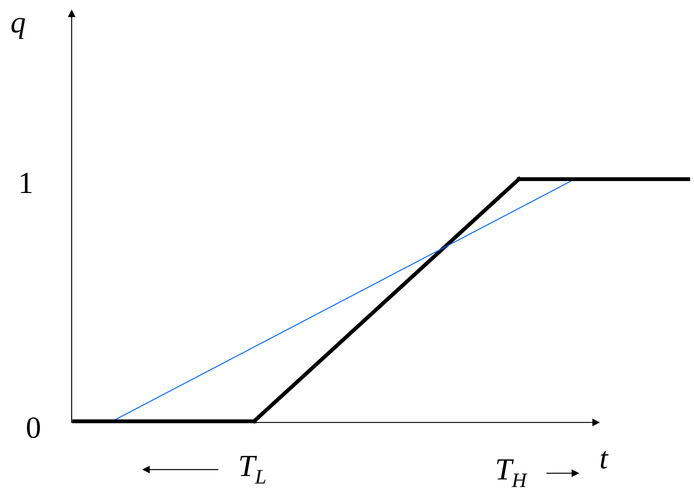


Figure 1: Impact of a tariff increase within an industry

This result is illustrated in Figure 1. The bold line represents the distribution of adoption dates prior to the imposition of a tariff on the industry (i.e., no one adopts, $q = 0$ until T_L when adoption begins and q increases until T_H when everyone has adopted and $q = 1$). As can be seen in Figure 1, the imposition of a tariff has the effect of speeding up the date of initial adoption (T_L) and delaying the date of final adoption (T_H), and thus extending the overall time of diffusion. However, as can be seen from Figure 1, the heterogeneity in tariff response across firms within an industry suggests that the *average* response to a tariff (i.e., whether a tariff increases or decreases productivity growth of the typical firm) is not clear cut. That is, whether a tariff speeds-up or delays adoption by the average firm (i.e., the firm adopting at the average adoption date) depends upon the point around which the distribution function rotates, which may not be the same for all industries. Thus, in the following section, we investigate how the marginal impact of a tariff change on productivity growth of the median firm is likely to vary across industries.

[11]Note that this result is relatively robust and holds for all non-prohibitive tariffs and it also holds when the number of foreign firms is assumed to be reduced by a change in the tariff ($dn_f < 0$).

3.2 Industry-level Heterogeneity in Tariff Response

If some firms are induced to adopt earlier by a tariff, while others adopt later a natural question is what happens to the typical or average firm? Does a tariff tend to raise or lower their productivity performance? As discussed in the introduction, empirical evidence on this question is mixed. Given that the same estimation techniques are employed in the empirical literature (and indeed one author appears on both sides of the evidence), what is it that distinguishes the situations where tariffs raise the productivity of the average firm, from those where it lowers productivity? To provide insight into this question, we characterize the behavior of the firm with the median adoption date.

The firm with the median adoption date, T_m is implicitly defined by:

$$\frac{1}{2} = \frac{1}{2} + \frac{(2\alpha - c))}{cn_h} + \frac{(2b-c)n_f}{2cn_h} + \frac{2(2+n)K'e^{rT_m}}{c^2 n_h} \tag{7}$$

$$\begin{aligned} \Rightarrow -K'e^{rT_m} &= \frac{(2(2\alpha - c) + (2b-c)n_f)c}{4(2+n)} \\ &= \frac{(A_1 + A_0 - c)c}{4} \end{aligned}$$

Since the LHS is declining in T_m, the median adoption date is negatively related to the value of the RHS. The behavior of the RHS with respect to a tariff change is given by:

$$\frac{c}{4(2+n)}\left(2n_f - \frac{dn_h}{db}\,(A_1 + A_0 - c)\right) \tag{8}$$

Calculation of $\frac{dn_h}{db}$ reveals.

$$\frac{dn_h}{db} = \left(\frac{\delta_0(A_0 - c) + \delta_1 A_1}{\delta_0(A_0-c)^2 + \delta_1 A_1^2}\right) n_f$$

Substitution gives:

$$\Rightarrow \quad \frac{cn_f}{4(2+n)}\left(1 - \frac{(\delta_0 + \delta_1)(A_0 - c)A_1}{\delta_0(A_0-c)^2 + \delta_1 A_1^2}\right)$$

This is negative (median adoption date increases) if:

$$\begin{aligned} \delta_0(A_0 - c)^2 + \delta_1 A_1^2 &< (\delta_0 + \delta_1)(A_0 - c)A_1 \\ \Rightarrow (A_0 - c - A_1)(\delta_0(A_0 - c) - \delta_1 A_1) &< 0 \end{aligned}$$

Since $(A_0 - c - A_1)$ is negative, the median adoption date will increase if the following condition is met:

$$\begin{aligned} \Rightarrow \frac{A_o - c}{A_1} &> \frac{\delta_1}{\delta_0} \\ \Rightarrow 1 - \frac{(2+n_f)c}{(2\alpha + bn_f)} &> \frac{e^{-rT_H}}{(1 - e^{-rT_L})} \end{aligned} \tag{9}$$

To evaluate this condition assume that it holds with equality, and then ask if a parameter change makes this condition more or less likely to hold. Note that the factors that influence whether or not this condition holds can be broken up into two broad groups. This division is based on the observation that all of the elements of the LHS are exogenous parameters (b, c, α) while the RHS is a function of two endogenous variables (T_L and T_H). Inspection of the list of exogenous parameters that influence the LHS reveals that one is missing, the size of entry costs (F). The characterization of the relationship between this factor and the productivity of the median firm is relatively straight forward. As was shown earlier, decreases in F tend to increase both T_L and T_H, which reduces the RHS. Consequently, industries that are relatively easy to enter are more likely to suffer a decline in the productivity of the median firm in response to a tariff. A similarly straight forward result holds for c. A smaller technology gap, clearly raises the LHS. It also decreases the RHS, since more firms are induced to enter, delaying both the start and the end of the adoption process. So an increase in the tariff is more likely to lower the productivity of the median firm if the technology gap is relatively small.

Characterization of the impact of the other parameters (b, α) is slightly more involved. Note that the above condition holds if:

$$\frac{(A_o - c)^2}{A_1^2} \geq \frac{\delta_1}{\delta_0} \tag{10}$$

Re-arranging implies:

$$\delta_0 \pi_0 \geq \delta_1 \pi_1 \tag{11}$$

From the Envelope Theorem we know:

$$\delta_0 \frac{d\pi_0}{db} > 0 \qquad \delta_1 \frac{d\pi_1}{db} < 0$$
$$\delta_0 \frac{d\pi_0}{d\alpha} > 0 \qquad \delta_1 \frac{d\pi_1}{d\alpha} < 0$$

Therefore, already high tariffs are likely to decrease the productivity of the median firm if they are increased any further. Similarly industries with a relatively large market (α), will also tend to experience slower productivity growth for the median firm in response to a tariff. Thus, the predictions of this section can be summarized as follows:

PROPOSITION 2 *A tariff increase is more likely to delay productivity-enhancing technology adoption by the median firm in industry i if:*

1. *barriers to entry are relatively low (lower F),*
2. *the productivity improvement from technology adoption is small (lower c),*
3. *tariffs are already relatively high (higher b),*
4. *the domestic market is relatively large (higher α).*

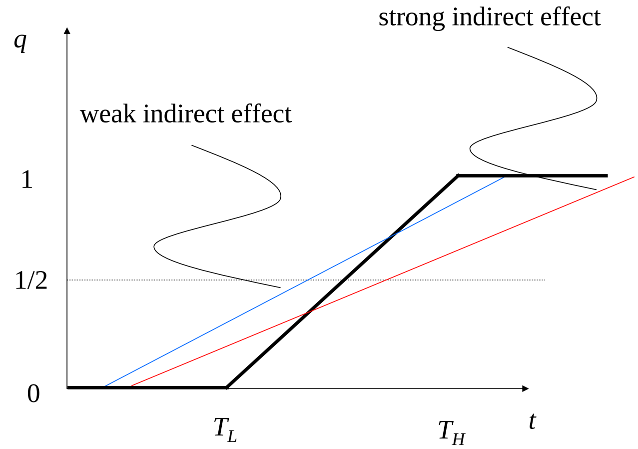


Figure 2: What happens to productivity for the majority of firms?

Note that the model predicts that the impact of a tariff change on the productivity of the median firm will not be uniform across industries. The intuition for this result derives from the conflict between the positive direct effect of trade barriers and the negative indirect effect and is illustrated in Figure 2. Specifically, in those industries where the indirect effect is relatively strong, a tariff increase is more likely to delay technology adoption by the median firm. For example, in industries where barriers to entry are relatively low, an increase in protection results in a relatively large increase in the number of firms. Thus, the indirect effect of a tariff change in such an industry is relatively strong, and, as can be seen in Figure 2, one is more likely to observe protection having a negative impact on the adoption decisions (and hence productivity) of the median firm. In contrast, industries where the indirect effect is relatively weak (high barriers to entry, large productivity gaps, low tariffs and small domestic markets) will observe a positive correlation between trade protection and productivity growth of a typical firm.

4 Colombian Trade Policy and Data Description

The model of the previous sections suggests a great deal of heterogeneity in the marginal impact of a tariff on the incentives of a firm to modernize and adopt new technologies. To investigate this heterogeneity, we focus on the case of Colombia. Like many developing countries, Colombia followed a policy of import substitution in the 1950's and 1960's. In the late 1970's this policy was reconsidered as Colombia sought entry into the GATT. Despite attaining membership in 1981, Colombian tariffs on manufactured goods were relatively high with the average tariff on manufactured goods around 50 percent in 1984. However from this relatively high level of protection Colombia systematically lowered its trade barriers through the 1980's and 1990's with an aim of creating a relatively uniform structure of protection that was comparable to those in developed countries. This change in trade policy provides variation not just in the level of protection but also the structure of protection across industries, making Colombia a particularly appealing setting in which to study the relationship between trade policy and productivity growth.[12]

Central to our analysis is the measurement of productivity. We follow Trefler (2004) and use labor productivity.[13] For our purposes labor productivity has a number of advantages over other measures of productivity, most notably TFP. In particular, the theoretical framework developed above emphasizes changes in technology that enhance labor productivity, making it a natural choice to focus on. Also if technological differences are an important source of heterogeneity among firms, the standard approach to measuring TFP, which relies on the estimation of a common industry level production function, tends to ignore these sources of structural difference. Finally, by focusing on the median response, which implies the use of quantile regression techniques, we put less emphasis on the precise measurement of productivity and more on the location of firms within the productivity distribution, with this ranking likely to be robust to different approaches to measuring productivity (see Levinsohn and Petrin (2003)). The definition of labor productivity we employ is real value added relative to the number of production workers.[14] As a measure of productivity growth we follow Trefler (2004) and consider long differences, with 1984 as our base year since in corresponds to the high point of average protection, and our end year is 1991, the final year of data that is available to us. Over this period, data is available for all manufacturing firms with at least 10 employees. For measures of trade liberalization, we employ ad-valorem tariff levels and effective rates of protection that are available at the 4 digit ISIC level. Note that we follow Fernandes (2006) and lag the tariff data one year relative to the productivity data to mitigate issues associated with the revenue based measure of productivity.[15]

The previous empirical approach to analyzing the link between trade policy and productivity is to regress changes in firm-level productivity on changes in trade barriers, typically controlling for some industry and/or firm characteristics. The usual hypothesis is that productivity is negatively related to tariffs, with inference based on an estimate of the average productivity impact of a change in trade policy across all firms in the sample. That is, a single coefficient is used to identify the

[12]For an overview of the evolution of trade policy in Colombia see Goldberg and Pavcnik (2005) and Fernandes (2006).

[13]While our methodology is common in the literature, it is not without its shortcomings. See Katayama, Lu, and Tybout (2006) for a recent critique.

[14]We would like to thank Mark Roberts for making the Colombian manufacturing census data available to us. For a complete description of all the variables used in our estimation, see the data appendix. For a description of this data set see Roberts (1996).

[15]The 4 digit ISIC tariff data is from Departamento Nacional de Planeacion and the matching trade data is from Departamento Administrativo Nacional de Estadistica. We would like to thank Jorge Garcia-Gracia at the World Bank for making this data available.

marginal impact of a tariff across both firms and industries. This methodology is motivated by a belief that competition increases productivity, though no formal models are developed to support this hypothesis. In contrast, we have shown that a plausible model of technology adoption by profit-maximizing firms suggests that the marginal impact is unlikely to be either uniform in size or sign. Thus, in the following sections we augment the previous empirical literature by using our theoretical framework as a guide to investigate the marginal response of productivity to tariffs along two dimensions: within-industry variation and across-industry variation.

5 Within-Industry Variation

In this section we consider whether the marginal impact of trade liberalization varies across firms within an industry. Note that Proposition 1 suggests that the impact of trade liberalization will not be uniform, instead firms that have the apparent advantage of relatively high productivity growth see this advantage further enhanced by a tariff, while those that appear to lag the technology frontier the most will find their relative productivity growth further disadvantaged by a tariff. Therefore the first step must be to determine which firm characteristics are associated with high productivity growth (early adoption) within an industry.[16] Here we follow an empirical strategy based on the previous literature (see Trefler (2004)), and regress firm characteristics on productivity growth. Therefore, productivity growth (from 1984 to 1991) for firm j in industry i, Δpr_i^j, is given by:

$$\Delta pr_i^j = \gamma_i + \beta_x X^j + \epsilon^j$$

where γ_i are 4 digit fixed effects and X^j are firm characteristics such as size, age, technology rank and exporter status.

Table 1 reports the determinants of the firm level productivity growth. The first column is a relatively standard firm level productivity growth equation, where the determinants of growth are: size, age, technology rank and exporter status (along with 4 digit fixed effects). All firm characteristics are taken from the Colombian manufacturing census. The size of the firm is the log of employment. The age of the firm is the log of the number of years since start-up. The technology rank is the difference between labor productivity for the plant and average labor productivity scaled by the standard deviation in labor productivity within the (4-digit ISIC) industry. Finally, exporter status is a dummy variable that takes the value of one if the plant is an exporter in 1984. The results suggest that larger firms, exporting firms and younger firms tend to have the highest productivity growth rates within industries. The only potentially surprising result is that productivity growth is negatively correlated with high initial productivity. However, this result is consistent with a story where firms already on the technology frontier have fewer options for further productivity growth, generating mean reversion between firms within an industry.

[16]Within the model, firms are indifferent about their exact location in the productivity distribution. Thus, the model provides no guidance about which firms will be the early adopters of new technologies, and which firms will be late adopters. Our approach is to identify these characteristics empirically.

The second column addresses the issue of selection of plants into the sample, since the growth rate can only be calculated for firms that survive until 1991. This column reports results for the standard Heckman selection methodology. The first stage probit includes all of the variables from the first column along with an exclusion restriction. In this case, the share of office equipment in total capital in 1984 forms a plausible restriction since this variable is unlikely to be directly related to the growth in productivity (since it is not part of the capital used in production), but is likely to be associated with a greater likelihood of exit. The greater likelihood of exit follows from the notion that firms with a greater share of capital tied up in unproductive assets are less likely to survive a negative shock. The results from a probit estimation are consistent with this conjecture, with the coefficient on office equipment negative and significant at the 5 percent level (see column 9, Table A.1). Returning to column 2 of Table 1, it is notable that the coefficient on the control for the selection probability, λ, is positive and significant. The positive λ implies that the shocks that influence survival are positively correlated with the shocks that generate productivity growth, a result that squares with expectations. With the exception of size, all of the remaining coefficients are relatively unaffected by the selection process. Furthermore, the standard errors are only slightly higher, with inference still concluding that all variables a statistically significant.

With the firm characteristics that determine productivity growth in hand we now revisit Proposition 1 which suggests potential heterogeneity in tariff response across firms within an industry. The intuition behind Proposition 1 suggests that if a characteristic contributes to high productivity growth, then when it is interacted with changes in trade barriers, productivity growth should be further enhanced (i.e. the interaction term should be have the same sign as the characteristic alone):

$$\Delta pr_i^j = \gamma_i + \beta_x X^j + \beta_{x*b} X^j \Delta b_i + \epsilon^j$$

- If $\beta_x > 0$ then $\beta_{x*b} > 0$
- If $\beta_x < 0$ then $\beta_{x*b} < 0$

where Δpr_i^j, is once again productivity growth for firm j in industry i, γ_i are 4 digit fixed effects and X^j are firm characteristics: size, age, technology rank and exporter status. Finally, Δb_i is the change in tariff barriers over the time period (lagged one year) for industry i.

Note that the above specification allows the marginal impact of a trade barrier to vary across firms within the industry. Specifically, it predicts that an increase in tariff barriers should result in larger firms, exporting firms and younger firms having higher productivity growth (i.e., have greater incentives to adopt new technologies) relative to other firms in the industry. Note that, since the estimated model includes four digit fixed effects, only firm level characteristics and their interactions can be included (i.e. tariff changes cannot be included separately).

The third column of Table 1 reports the results of the firm level productivity growth estimates when tariff change interaction terms are included for all of the firm level characteristics. All the interaction terms have the same sign as the growth generating characteristics when entered alone.

This matches the prediction that firms with the potential for higher productivity growth benefit from a tariff, while those with low growth potential are hurt (remember that this is within an industry). Furthermore, the interaction terms on age and exporter status are statistically significant. Thus, the results suggest that larger firms, exporting firms and younger firms are more likely to receive any of the productivity benefits from tariffs. Column 4 confirms that these results are not altered when accounting for selection.[17] Furthermore, the signs and significance of these interactions terms are relatively robust to the time period considered, the use of lagged tariffs or effective rates of protection and which interaction terms are included (see Table A.1 in the appendix).

To gain insight into the economic significance of the interaction terms consider a high growth firm which is one standard deviation above the mean in terms of size, and one standard deviation below the mean in terms of age. Such a firm is predicted to have productivity grow by 0.4 of a percent per annum faster relative to the mean in the presence of a 20 percent tariff increase. Given the symmetry of the estimates, a low growth firm one standard deviation below the mean in terms of size, and one standard deviation above the mean in terms of age would have productivity grow 0.4 of a percent slower, generating almost a one percentage point differential. This implies relatively large differences across firms within the same industry. Overall, table 1 provides evidence that within industries firms have a differential response to tariffs that is both statistically and economically significant, with the heterogeneity consistent with the predictions of Proposition 1.

6 Across Industry Variation

While Proposition 1 predicts heterogeneity in the tariff response across firms within an industry, Proposition 2 suggests the presence of heterogeneity in tariff response across industries. In particular it says that whether or not the majority of firms in an industry improve their productivity performance when a tariff is applied depends on the characteristics of the industry (i.e. the impact of a given tariff change varies across industries; so the tariff change should be interacted with industry characteristics). Thus, in this section we investigate whether the marginal impact of trade liberalization on the productivity growth of the median firm is conditional on industry-level characteristics.

In this respect, our theory provides some guidance as Proposition 2 suggest some explicit industry characteristics that should be related to the strength of the indirect effect and thus the marginal impact of a tariff change. To measure these characteristics, we follow convention as closely as possible. Barriers to entry (F_i) are measured as the negative of the average annual entry rate in a four digit industry (a lower entry rate is associated with higher barriers to entry).[18] The technology gap (c_i) is defined as the difference between the productivity of the most productive firm and the least productive firm scaled by the productivity of the least productive firm within an industry.

[17] The first stage regression is the same one used in column 2. For the purposes of consistently, whenever an equation includes a control for the selection effect in Tables 1 or 2, the equation from column 9 of Table A.1 is used.

[18] Annual entry rates are calculated for the period 1977-82, and then averaged. Over this period, all firms are reported in the dataset without a 10 employee cut-off.

Relative market size (α_i) is measured as the expenditure on an industry relative to spending on all manufacturing. All of these measures are drawn from the Colombian census of manufactures and use data from 1984 or earlier. Thus, the empirical model is:

$$\Delta pr_i^j = \gamma_i + \beta_0 \Delta b_i + \beta_1 F_i \Delta b_i + \beta_2 c_i \Delta b_i + \beta_3 b_i \Delta b_i + \beta_4 \alpha_i \Delta b_i + \beta_x X^j + \beta_z Z_i + \epsilon^j \tag{12}$$

where Δpr_i^j, is once again productivity growth for firm j in industry i, γ_i are 2 digit fixed effects, X^j are firm characteristics and Z_i are industry characteristics. Finally, Δb_i is the change in tariff barriers over the time period (lagged one year) for industry i.

The key predictions of Proposition 2 are, first, that a tariff increase is more likely to encourage adoption by the median firm in industries where barriers to entry (F_i) are high (i.e., $\beta_1 > 0$). Second, that the median firm's response to a tariff increase is likely to be positive in industries with larger technology gaps (c_i) and lower tariffs (i.e., $\beta_2 > 0$ and $\beta_3 < 0$). Finally, the model predicts that tariffs increase productivity growth of the majority of firms in industries where the size of the domestic market (α_i) is smaller (i.e., $\beta_4 < 0$).

Before we explore potential heterogeneity in the marginal productivity impact of a tariff change, we benchmark our methodology. The first column of Table 2 reports the results from the standard approach using ordinary least squares techniques, controlling for firm characteristics and two digit industry fixed effects. In line with the results from Fernandes (2006), who also investigates the impact of trade liberalization in Colombia on firm productivity, the first column reports that firms in industries that experienced larger tariff reductions had greater mean productivity growth. To gain insight into what might be driving this response and also move the estimation technique closer to one suitable for exploring our theoretical predictions (since these relate to the median rather than the mean), the second column reports the results from a median regression with the same specification as column 1 otherwise. Now we see that tariff reductions are associated with lower productivity growth. While the difference in sign is not likely to be significant, it does have two immediate implications. First it underscores the importance of heterogeneity in the data, with different methodologies producing different results. Second, it also cautions that outliers are likely to have played an important and under appreciated role in the results of previous studies. Since there is a large degree of heterogeneity in the data, concerns are naturally raised about a specification that assumes the marginal effect is the same for all firms both within and across industries. Indeed, there is no theoretical reason to expect a uniform marginal response, and our theoretical analysis provides strong reasons to expect the existence of non-linearities in the correlation between tariff changes and firm productivity growth. We now augment the standard empirical specification by considering these possibilities.

To investigate how the response of the median firm varies across industries we include the interaction terms in the specification as suggested by equation (12).[19] The results are presented in

[19] In addition to including industry characteristics (size, barriers to entry, initial tariffs and technology gap) in the interaction terms, we also include these industry characteristics as separate, linear terms in the estimation.

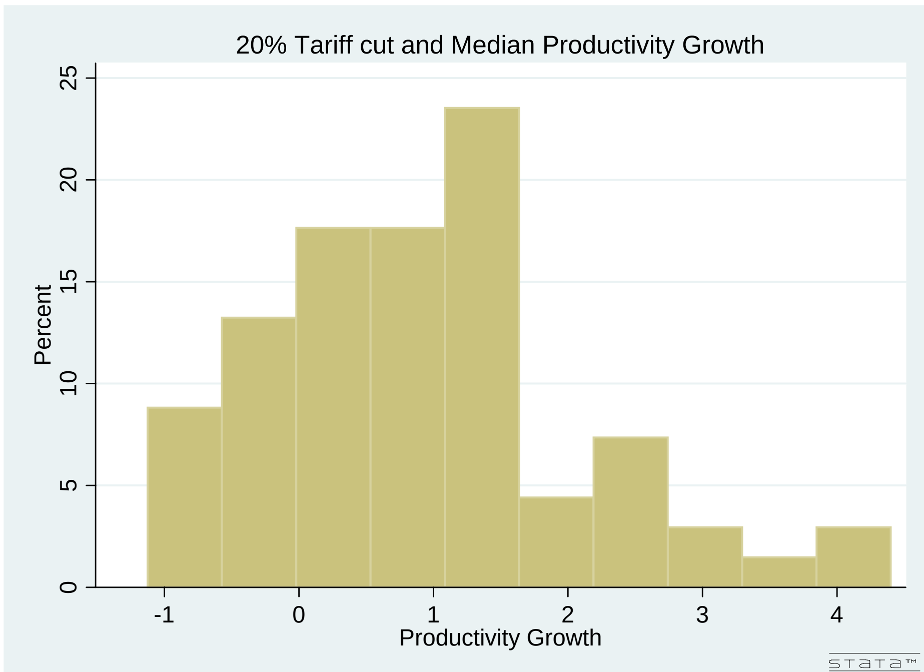
column 3 of Table 2. To standardize the interpretation of the estimated coefficients, all of the industry characteristics have been centered at zero. In this case, the impact of a tariff change on the median firm in an industry with average sample characteristics is given by the tariff change term alone. By centering the data in this way, we see that the median firm in the average industry is predicted to have lower productivity growth due to trade liberalization. However, the model developed above does not predict a uniform response to tariff changes, so focusing on the predicted outcome for the average industry is unlikely to provide any general insights. Instead the model predicts that industry characteristics will be important in determining whether the majority of firms within an industry respond to tariff changes by raising or lowering their productivity growth. This places primary importance on the signs and significance of the interaction terms. In this respect all the coefficients on the interaction terms in column 3 have the predicted signs (that a tariff decrease is more likely to encourage productivity improvements in industries with low barriers to entry, small technology gaps, high tariffs and large domestic market size). Moreover, all four interaction terms are statistically significant.

However, one concern might be that the results are biased due to the presence of the sample selection issue discussed previously. Given the use of quantile regression, the standard Heckman correction doesn't apply. In this case we follow the methodology set out in Buchinsky (1998). This involves approximating the unknown correction term in the second stage by a polynomial expansion of a first stage index.[20] From the results reported in column 4, it is clear that the parameter estimates are relatively unaffected by the inclusion of a control function for sample selection. To provide a more familiar benchmark, column 5 reports results from mean regression while column 6 reports the results from the standard Heckman correction. Reassuringly, all the coefficients have the predicted signs and three of the four interaction terms are statistically significant. Once again, there is little difference between the coefficients and the standard errors in the corrected and uncorrected models, suggesting that sample selection is not driving the results. Furthermore, the signs and significance of these interactions terms are relatively robust to the time period considered, the use of lagged tariffs or effective rates of protection and which interaction terms are included (see table A.2 in the appendix for details). These results confirm the presence of significant heterogeneity in the median tariff response, with such variation being consistent with the predictions of our model of endogenous technology adoption.

To gain insight into whether these interaction terms are of economic significance, we use the estimates to predict how each industry would be affected by a 20 percentage point tariff cut. As can be seen in the graph below, for the majority of industries the productivity growth of the median firm increases as a result of the tariff cut. More importantly the histogram also provides a sense of the diversity of response embodied in the data. In this graph the x-axis lists the predicted annual compound growth rates for the median firm. For three quarters of the Colombian manufacturing

[20]For the purposes of consistency a quadratic involving the inverse mills ratio was used based on the probit equation in column 9, Table A.1. A number of other specifications we used to check for robustness, with the results relatively stable across specifications.

industries a 20 percentage point reduction in tariffs has a positive impact on productivity growth for the majority of firms. In fact, it is predicted that a quarter of all industries have the majority of firms raising their productivity growth by over 2 percentage points due to lower tariffs. However, for a quarter of the Colombian manufacturing sector, the median firm experiences slower productivity growth. This suggests a very diverse response to trade liberalization across industries. Thus, the cross industry variation appears to be not only statistically important but also economically important as well.



While the histogram gives a sense of the diversity of behavior across industries in relation to the median, the theoretical model can also be used to characterize other parts of the distribution, generating further predictions to be investigated. In particular, it is straight forward to show that Proposition 2 generalizes to other quantiles of the productivity distribution. Therefore, the interaction terms are predicted to have the same sign regardless of which quantile is considered. To assess this prediction, the seventh and eighth columns of Table 2 report results of the first and third quartile regressions. In line with the theory all the interaction terms have the predicted signs. Furthermore, for both the first and third quartiles the interaction terms involving barriers to entry, technology gaps and industry size are statistically significant. Given the lack of structure imposed on the data by the quantile regression technique, the relative success of these ancillary theoretical predictions offers solid support for the robustness of the mechanism outlined in our theoretical model. Overall the estimates in these tables show that the factors that the theory predicts should be important for determining variation in response to tariff changes across industries, are in fact important in the data.

7 Conclusion

A central issue in the trade policy literature is the relationship between trade policy and firm productivity. An older view assumed that tariffs would allow domestic firms to capture a larger market share, thereby encouraging domestic firms to invest in better technology. However, more recently emphasis has been placed on the productivity enhancing effects of foreign competition as it drives out inefficient domestic firms and prompts the surviving firms to modernize. While determining which view is correct is essentially an empirical question, the mixed results in the existing literature suggest that a simple empirical strategy is not sufficient to identify the underlying mechanisms. In this paper we developed a model that captures an essential feature of the data; firms, even within narrowly defined industries, have very different characteristics, including productivity. This observation suggests that firms within the same industry may react very differently to changes in trade policy, making it difficult to identify the behavior of a 'typical' firm without an understanding of the source of the firm heterogeneity. By developing a theoretical model that provides insight into this heterogeneity we are able to characterize the differential response to tariffs not only by firms within industries but also by firms across industries.

To investigate these predictions we examine the Colombian experience with trade liberalization since the mid 1980's. Not only did Colombia undertake a substantial program of unilateral trade liberalization that resulted in a large fall in the average tariff on industrial goods, but the structure of protection was also dramatically altered. In this setting we found that trade liberalization tended to raise the productivity of the typical firm in industries with low barriers to entry, small technology gaps, large markets and also large initial levels of protection. By including these industry characteristics we are able to provide a more nuanced view of how industries are likely to vary in their response to trade liberalization. However, we also found evidence that firms within industries also had a differential response to tariff changes, not just in terms of magnitude of response but in terms of whether it improved or undermined a firms productivity performance. Specifically we found that larger firms, younger firms and exporting firms (i.e., firms with high rankings in the productivity distribution) tended to grow faster as tariffs are raised. Finally, we show that such variation across firms and across industries is consistent with a our model of endogenous technology adoption. Thus, the results of this paper (both theoretical and empirical) highlight the fact that the relationship between tariffs and productivity is not likely to be a simple one and will vary not only across industries but also within industries.

A Data

All firm data are taken from a plant-level dataset produced from the Colombian Manufacturing census by DANE (National Statistical Institute) for the years 1977 through 1991. From 1983 the census covers industrial production for plants with greater than 10 employees. Our empirics concentrate on plants which were operating in both 1984 and 1991. For a thorough description of this dataset see Roberts (1996).

A.1 Firm Characteristics

Productivity Growth: the compound rate of change in labor productivity from 1984 to 1991. Labor productivity is measured as real-value added for the plant divided by the number of production workers (total employment minus owners and management staff).
Size: the log of employment. This characteristic is centered at zero by subtracting out the average size of the plants within the sample.
Age: the log of the number of years since the start up of the plant to the year 1984. This characteristic is centered at zero by subtracting out the average age of the plants within the sample.
Technology Rank: the difference between labor productivity for the plant and average labor productivity in the (4-digit ISIC) industry. This difference is scaled by the standard deviation of labor productivity within the industry.
Exporter Status: a dummy variable that takes the value of one if the plant exported in 1984.

A.2 Industry Characteristics

Tariff: ad-valorem tariff at the 4-digit ISIC level. Provided by Jorge Garcia at the World Bank. The tariff change for a 4-digit industry is simply the difference between 1990 and 1983 ad-valorem tariffs.
Entry Costs: the negative of the average annual entry rate within a 4-digit ISIC industry over the period 1977-82. This characteristic is centered at zero by subtracting out the average entry rates of all industries within the sample.
Technology Gap: the difference between the maximum and minimum labor productivities of plants within a 4-digit ISIC industry in 1984. This difference is scaled by the productivity of the least productive plant within the industry.
Industry Size: the ratio of total domestic sales for a 4-digit ISIC industry in 1984 to total domestic sales for all industries in the sample. Total domestic sales are found by summing sales for all plants at the 4-digit ISIC level and then adding in total imports for the industry (import data is provided by Jorge Garcia at the World Bank). This characteristic is centered at zero by subtracting out the average industry size of all industries within the sample.

Reference

Amiti, M. and Konings, J. (2005). Trade liberalization, intermediate inputs, and productivity: evidence from indonesia. IMF Working Papers, 5/146.

Baggs, J., Head, K., and Ries, J. (2002). Free trade, firm heterogeneity and canadian productivity. manuscript.

Bagwell, K. and Staiger, R. W. (1992). The sensitivity of strategic and corrective r&d policy in battles for monopoly. *International Economic Review*, *33*, 795–816.

Brooks, E. (2006). Why don't firms export more? product quality and colombian plants. *Journal of Development Economics*, *80*, 160–178.

Buchinsky, M. (1998). The dynamics of change in the female wage distribution in the usa: a quantile regression approach. *Journal of Applied Econometrics*, *13*, 1–30.

Bustos, P. (2006). Rising wage inequality in the argentinean manufacturing sector: the impact of trade and foreign investment on technology and skill upgrading. Working paper, Universitat Pompeu Fabra.

Conway, P. (2006). Downsizing, layoffs and plant closure: the impacts of import price pressure and technological improvements on us textile producers. Working paper, University of North Carolina.

Crowley, M. A. (2006). Do safeguard tariffs and antidumping duties open or close technology gaps?. *Journal of International Economics*, *68*, 469–484.

Ederington, J. and McCalman, P. (2006). Endogenous firm heterogeneity and the dynamics of trade liberalization. manuscript.

Fernandes, A. (2006). Trade policy, trade volumes and plant-level productivity in colombian manufacturing industries. *Journal of International Economics*.

Fudenberg, D. and Tirole, J. (1985). Preemption and rent equalization in the adoption of new technology. *Review of Economic Studies*, *52*, 383–401.

Goldberg, P. and Pavcnik, N. (2005). Trade, wages, and the political economy of trade protection: evidence from the colombian trade reforms. *Journal of International Economics*, *66*, 75–105.

Götz, G. (1999). Monopolistic competition and the diffusion of new technology. *Rand Journal of Economics*, *30*, 679–693.

Katayama, H., Lu, S., and Tybout, J. (2006). Firm-level productivity studies: illusions and a solution. Working paper.

Konings, J. and Vandenbussche, H. (2004). Antidumping protection and productivity growth of domestic firms. CEPR Discussion Papers 4620.

Krishna, P. and Mitra, D. (1998). Trade liberalization, market discipline and productivity growth: new evidence from india. *Journal of Development Economics*, *56*(2), 447–462.

Levinsohn, J. and Petrin, A. (2003). Estimating production functions using inputs to control for unobservables. *Review of Economic Studies*, *70*, 317–342.

Miyagiwa, K. and Ohno, Y. (1995). Closing the technology gap under protection. *American Economic Review*, *85*, 755–770.

Muendler, M.-A. (2004). Trade, technology, and productivity: a study of brazilian manufacturers, 1986-1998. University of California at San Diego, Economics Working Paper Series, 2004-06.

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

Reinganum, J. (1981). On the diffusion of new technology: a game theoretic approach. *Review of Economic Studies*, *48*, 395–405.

Roberts, M. J. (1996). Colombia, 1977-85: producer turnover, margins, and trade exposure. In Roberts, M. J. and Tybout, J. R. (Eds.), *Industrial Evolution in Developing Countries: Micro Patterns of Turnover, Productivity, and Market Structure*, pp. 227–259. Oxford University Press.

Rodrik, D. (1992). Closing technology gaps: does trade liberalization really help?. In Helleiner, G. (Ed.), *Trade Policy, Industrialization and Development: New Perspectives*. Claredon Press.

Syverson, C. (2004). Product substitutability and productivity dispersion. *Review of Economics and Statistics*, *86*, 534–550.

Trefler, D. (2004). The long and short of the canada-u.s. free trade agreement. *American Economic Review*, *94*, 870–895.

Tybout, J. R. (2002). Plant and firm-level evidence on new trade theories. In Harrigan, J. (Ed.), *Handbook of International Economics*. Basil Blackwell.

Yeaple, S. (2005). A simple model of firm heterogeneity, international trade, and wages. *Journal of International Economics*, *65*, 1–20.

Table 1
Impact of Tariffs on Firm Productivity Growth – Within Industry Variation
Colombian Manufacturing Sector, 1984-1991

	(1)	(2)	(3)	(4)
	OLS	Heckman	OLS	Heckman
Size	1.87***	3.05***	2.00***	3.17***
	(0.22)	(0.68)	(0.29)	(0.70)
Size*ΔTariff			0.01	0.01
			(0.01)	(0.01)
Tech Rank	-2.72***	-2.39***	-2.80***	-2.48***
	(0.19)	(0.27)	(0.27)	(0.33)
Tech Rank*ΔTariff			-0.004	-0.01
			(0.01)	(0.01)
Age	-0.77***	-0.62**	-1.08***	-0.95***
	(0.23)	(0.26)	(0.32)	(0.33)
Age*ΔTariff			-0.02*	-0.02*
			(0.01)	(0.01)
Exporter in 1984	2.49***	2.16***	3.59***	3.30***
	(0.63)	(0.68)	(0.85)	(0.90)
Exporter*ΔTariff			0.08*	0.08**
			(0.04)	(0.04)
4 Digit Effects	Yes	Yes	Yes	Yes
λ		6.57*		6.90*
		(3.58)		(3.73)
R-squared	0.13		0.14	
Observations	3388	3382	3388	3382

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
Tariffs and tariff changes are lagged one period.

Table 2
Impact of Tariffs on Firm Productivity Growth – Across Industry Variation
Colombian Manufacturing Sector, 1984-1991

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	Median	Median	Med/Selection	OLS	Heckman	1st Quartile	3rd Quartile
ΔTariff	-0.01	0.01	0.20***	0.18**	0.11	0.10	0.24***	0.06
	(0.02)	(0.02)	(0.07)	(0.08)	(0.09)	(0.09)	(0.09)	(0.10)
Entry*ΔTariff			0.8***	0.6*	1.0***	1.0***	1.0***	0.7*
			(0.3)	(0.3)	(0.4)	(0.4)	(0.4)	(0.4)
Gap*ΔTariff			0.01***	0.01***	0.005*	0.005*	0.008***	0.008**
			(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)
Ind. Size*ΔTariff			-4.6***	-4.7***	-2.8**	-2.8**	-5.6***	-4.3***
			(1.1)	(1.2)	(1.3)	(1.4)	(1.3)	(1.6)
Tariff*ΔTariff			-0.001**	-0.001**	-0.0002	-0.0002	-0.0002	-0.0005
			(0.000)	(0.001)	(0.001)	(0.001)	(0.0006)	(0.0007)
Linear terms			Yes	Yes	Yes	Yes	Yes	Yes
Observations	3388	3388	3388	3382	3388	3382	3382	3382
R-squared	0.09				0.10			
Pseudo R-sq		0.05	0.07					

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
All estimated equations include 2 digit effects and firm level characteristics: size, age, exporter status, technology rank.
Entry, Gap, Ind. Size and Tariff have all been centered at zero.
Tariffs and tariff changes are lagged one period.

Table A.1
Impact of Tariffs on Firm Productivity Growth – Within Industry Variation
Colombian Manufacturing Sector, Robustness and Sensitivity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Size	3.19***	3.25***	3.92***	4.00***	3.05***	3.07***	3.16***	2.98***	0.38***
	(0.71)	(0.71)	(0.79)	(0.71)	(0.68)	(0.69)	(0.69)	(0.68)	(0.02)
Size*ΔTariff	0.003	0.001	0.005	0.003	0.004				
	(0.008)	(0.005)	(0.01)	(0.02)	(0.011)				
Tech Rank	-2.517***	-2.505***	-3.89***	-2.84***	-2.41***	-2.42***	-2.37***	-2.41***	0.12***
	(0.388)	(0.304)	(0.41)	(0.34)	(0.27)	(0.31)	(0.27)	(0.27)	(0.02)
Tech Rank*ΔTar	-0.003	-0.004	-0.03***	-0.016		-0.002			
	(0.007)	(0.004)	(0.01)	(0.016)		(0.01)			
Age	-1.14***	-0.808***	-0.50	-0.92***	-0.62**	-0.62**	-0.87***	-0.60**	0.04*
	(0.41)	(0.298)	(0.46)	(0.34)	(0.25)	(0.25)	(0.32)	(0.25)	(0.02)
Age*ΔTariff	-0.01*	-0.01*	-0.002	0.010			-0.015		
	(0.005)	(0.005)	(0.011)	(0.02)			(0.01)		
Exporter	3.27***	3.170***	1.64	2.39**	2.17***	2.15***	2.12***	3.16***	0.05
	(0.90)	(0.793)	(1.19)	(0.95)	(0.68)	(0.68)	(0.69)	(0.87)	(0.08)
Exporter*ΔTariff	0.08*	0.04**	0.022	0.01				0.07*	
	(0.04)	(0.02)	(0.03)	(0.06)				(0.04)	
Office Equip									-0.33**
									(0.15)
Observations	3382	3297	3915	3593	3382	3382	3382	3382	5565

Standard errors in parentheses: * significant at 10%; ** significant at 5%; *** significant at 1%
Size, tech rank and Age have all been centered at zero. All estimated equations included 4 digit fixed effects and correct for selection.
(1) Contemporaneous tariffs are used rather lagged tariffs.
(2) Effective rates of protection are used in place of tariffs.
(3) Data covers period 1985 to 1991.
(4) Data covers period 1984 to 1990.
(5) - (8) Interaction terms considered individually.
(10) Selection equation used in Tables 1 and 2.

Table A.2
Impact of Tariffs on Firm Productivity Growth – Across Industry Variation
Colombian Manufacturing Sector,
Robustness and Sensitivity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ΔTariff	0.01	0.10***	0.22***	0.48***	0.24***	-0.09**	-0.01	0.02
	(0.06)	(0.03)	(0.07)	(0.09)	(0.06)	(0.04)	(0.03)	(0.05)
Entry*ΔTariff	0.7***	0.5***	0.9***	1.8***	1.3***			
	(0.2)	(0.2)	(0.3)	(0.4)	(0.2)			
Gap*ΔTariff	0.005***	0.004***	0.22	0.16***		0.002		
	(0.001)	(0.001)	(0.33)	(0.03)		(0.002)		
Ind. Size*ΔTar	-2.2***	-1.6***	-4.0***	-11.7***			-4.0***	
	(0.8)	(0.6)	(1.0)	(1.7)			(0.8)	
Tariff*ΔTariff	-0.0002	-0.0001**	-0.0008*	-0.0007				-0.001***
	(0.0003)	(0.0001)	(0.0004)	(0.0008)				(0.000)
Linear terms	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3379	3294	3946	3629	3415	3382	3382	3382

Standard errors in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%
All estimated equations include 2 digit effects and firm level characteristics: size, age, exporter status, technology rank.
Entry, Gap, Ind. Size and Tariff have all been centered at zero.
All equations include a control function to correct for selection.
(1) Contemporaneous tariffs are used rather lagged tariffs.
(2) Effective rates of protection are used in place of tariffs.
(3) Data covers period 1985 to 1991.
(4) Data covers period 1984 to 1990.
(5) - (8) Interaction terms considered individually.