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# Trade and market selection: Evidence from manufacturing plants in Colombia ☆

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ABSTRACT

We examine the link between trade liberalization and aggregate productivity, with a focus on improved market selection resulting from a reduction in trade barriers and in the dispersion of these barriers across producers. Our analysis exploits tariff changes across sectors after the Colombian trade reform. An additional advantage of our analysis is that our TFP measure does not include demand and price effects. We find that reduced trade protection makes plant survival depend more closely on productivity. Using a dynamic simulation, we find that enhanced selection increases aggregate productivity substantially. Trade liberalization also increases productivity of incumbent plants and improves the allocation of activity. We find larger effects on allocative efficiency with our TFP measure than with a traditional measure including price effects.

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## 1. Introduction

A recent literature stresses the idea that policies which misallocate resources across heterogeneous producers can negatively affect aggregate productivity.[1] This idea has figured prominently in recent analyses of trade reform. For example, in a model where productivity is the only determinant of profitability, Melitz (2003) shows theoretically that trade liberalization causes low productivity firms to exit, thereby reallocating inputs to more productive firms and increasing aggregate

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[1] Poor institutions—including trade barriers that are differential across producers—generate misallocation by introducing idiosyncratic distortions to profitability (Banerjee and Duflo, 2005; Bartelsman et al., forthcoming; Hsieh and Klenow, 2009; and Restuccia and Rogerson, 2008). Survival and growth may then depend on idiosyncratic policies, such as favorable trade regulations, rather than on efficiency.

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productivity. Subsequent empirical work has confirmed that trade liberalization is indeed associated with increases in exit.[2] However, this work has not examined the link between the increased exit and plant-level productivity, a link that is absolutely central to the issue of whether the increased exit is associated with productivity improvements. The goal of this paper is to present evidence on this link—termed here the "market selection" mechanism—using a high quality plant-level data set for Colombia that spans two decades in the middle of which a major trade reform occurred.

Two considerations serve to conceptually motivate our empirical exercise. First, in an economy driven solely by market forces (e.g., Hopenhayn, 1992), plant exit will be perfectly determined by what we call here "market fundamentals": plant characteristics related to the plant's efficiency, and to the industrial organization in its output and input markets. One of these market fundamentals is productivity: plant exit should be perfectly negatively correlated with plant productivity in an efficient market economy.[3] Second, in reality plant exit will also be influenced by non-market industry-specific (and even plant-specific) factors such as idiosyncratic subsidies or tariffs, thereby weakening the empirical relationship between productivity and exit (e.g., Restuccia and Rogerson, 2008). In the Colombian context, a key feature of the trade reform was that it not only reduced the average level of tariffs, but also that it greatly diminished the variation in tariffs across industries. With this in mind, our empirical strategy is to assess the extent to which the relationship between productivity and exit was strengthened by the trade reform in Colombia, taking advantage of cross sectoral variability in tariffs. Specifically, we examine the change in the relationship between plant productivity and plant exit as tariffs in the plant's sector go down from the pre-reform period to the post-reform period. We then move on to consider the resulting effect of trade-induced exits on aggregate productivity.

A key feature of our empirical analysis is that we are able to distinguish between two different measures of productivity: physical productivity, or TFPQ, and revenue productivity, TFPR. Since plant-level deflators for inputs and output are not available in most plant-level databases, previous related studies have measured productivity through TFPR. This approach confounds producer-level technical efficiency (TFPQ) and producer-level prices, and can potentially be quite misleading to the extent that producer-level prices are endogenous. While researchers have been aware for some time of the potential problems of using TFPR to evaluate theories that refer to TFPQ, little is known about the actual size and even the direction of the biases introduced by this source of mismeasurement. In this context, a key additional advantage of the Colombian data is the availability of plant-level price deflators for outputs and inputs, that permit distinguishing between TFPQ and TFPR measures. We take advantage of this richness of the data not only to examine the effect of trade liberalization using TFPQ measures, but also to provide a quantitative analysis of the differences in estimated effects when TFPR is used instead of TFPQ.[4]

Four main findings emerge from our study. First, we find a significant increase in the connection between productivity and exit as we move from the pre-reform period to the post-reform period, with the marginal effect of physical productivity on survival increasing more in those sectors facing the largest tariff reductions. The magnitude of the improvement in the market selection mechanism is large. For example, the marginal effect on the probability of exit of a one-standard-deviation increase in productivity goes up (in absolute value) by 0.4 percentage points when tariffs decrease from 60% to 20%; this is a large impact when compared to an average 8% exit rate. Second, the increased connection between exit and productivity is associated with important gains in aggregate productivity. A dynamic simulation yields an estimated gain of 2.1 log points in average productivity over five years, directly attributable to improved market selection with actual tariffs relative to pre-reform tariff levels. Third, the trade reform in Colombia was also associated with an increase in within-establishment physical productivity of about 3 log points and with better overall resource allocation: correlations between plant market shares and plant physical productivities go up as tariffs in the respective sector go down. And fourth, we find that results based on TFPQ differ substantially from those obtained using TFPR. When using TFPR we find mixed or diminished results of the impact of trade liberalization on aggregate productivity. In particular, when using TFPR we do not find a significant change in the productivity-exit relationship due to trade liberalization, and we find a mitigated quantitative impact of the reform on both within-establishment productivity growth and general allocative efficiency.

The impact of greater trade on plant exit rates has been the focus of recent research taking advantage of rich longitudinal plant-level data. Most previous studies examine the direct effect of multinational ownership or tariffs on the probability of survival (e.g., Gibson and Harris, 1996; Baggs, 2005; and Bernard and Jensen, 2007).[5] By contrast, we focus on the impact of trade on the link between plant productivity and plant exit. Our focus highlights that a key component of successful trade reform is a reduction of the dispersion in levels of protection from trade. This has crucial policy implications in today's world: in evaluating future trade reform, greater attention should be paid to the dispersion of remaining protection across businesses.

[2] For instance, Gibson and Harris (1996), Head and Ries (1999), Baggs (2005), Bernard and Jensen (2007), Alvarez and Vergara (2010), Palangkaraya and Yong (2011).

[3] The other, theory-motivated, market fundamentals we have in mind are demand shocks, demand elasticities, and input costs. These are controlled for in our empirical analysis.

[4] Building on a theoretical framework and data on products at the plant level, De Loecker (2011) corrects for unobserved prices in estimating the impact of trade on within-plant productivity. He finds that this effect halves when controlling for prices and mark-ups rather than using standard productivity measures. We look at the related issue of how access to plant-level prices affects results regarding market selection. We also re-examine De Loecker's results imposing less restrictions on the structure of the data, and arrive at similar conclusions.

[5] A recent exception is the paper by Bloom et al. (2011), who find that firms with better technology are less likely to exit in response to the changes in Chinese imports.

Pavcnik (2002), Trefler (2004), and many others, have previously documented increases in productivity in response to trade reform.[6] This paper contributes to that literature not only by exploring in detail the question of potentially improved market selection but also by isolating the effect of trade liberalization from that of other contemporaneous reforms. We do this by taking advantage of cross-sectional variation in both tariffs and tariff changes. Lileeva and Trefler (2010) have recently also used cross-sectional variability in tariff changes to identify effects of trade liberalization, focusing on labor productivity and innovation investments (in contrast to our focus on plant exit and, subsequently, aggregate TFP).

This paper is also related to our own previous work using the same database. In Eslava et al. (2004, 2006, 2010a) we develop the empirical structure and methodology for decomposing revenue productivity into physical productivity and price components. Our earlier work also showed that key aspects of firm dynamics changed after the market reforms: adjustment dynamics for capital and labor became more flexible, and the marginal effects of measures of profitability on exit increased (Eslava et al., 2010a, 2006, respectively). But this earlier work looked at mean differences between the pre-reform and post-reform periods, while the current paper exploits rich cross-sectional variation in the extent of trade reform to disentangle the effects of trade liberalization from other contemporaneous changes, and to examine the impact of removing idiosyncratic distortions. The joint set of past and current results from this research agenda points at important gains in allocative efficiency stemming from market reforms in Colombia, because of more flexible and efficient adjustment in both intensive and extensive margins.

The rest of the paper proceeds as follows. In Section 2, we discuss the theoretical considerations that motivate our empirical analysis. Section 3 explains the data we use from the Annual Manufacturing Survey as well as the trade data. In Section 4, we present estimates of the effects of productivity and other market fundamentals on plant exit, and how trade reform changes these effects. Section 5 addresses the implications of trade-related exits for average productivity, and puts them in perspective by exploring alternative effects of tariff reductions on productivity. Robustness tests are presented in Section 6. We conclude in Section 7.

## 2. Theoretical considerations

Start by considering a healthy (i.e., non-distorted) economic environment, where exit is a result of plant-level market fundamentals. Recent models (e.g., Melitz and Ottaviano, 2008; and Foster et al., 2008) emphasize that many market fundamentals, including but not limited to productivity, influence variation in profitability across producers. We draw upon that recent literature in developing our empirical strategy. A key component of this empirical strategy is disentangling revenue productivity into its physical productivity and price components. In this section, we present an economic environment where this distinction is important and, in turn, consider the implications of the recent literature on the nature of firm dynamics and idiosyncratic distortions in such an environment.

Consider the following characterization of the determinants of plant-level profitability.[7] Let production be determined by:

$$Y_{it} = A_{it} x_{it}^{\theta},$$

where $Y_{it}$ is output, $A_{it}$ is technical efficiency, $x_{it}$ is a composite input, and $\theta \leqslant 1$ is the returns to scale parameter. Plants face downward sloping demand curves given, in inverse form, by:

$$P_{it} = D_{it} Y_{it}^{-(1/\eta_{it})},$$

where $P_{it}$ is the price, $D_{it}$ is an idiosyncratic demand shock, and $\eta_{it}$ is the demand elasticity that could be idiosyncratic and time varying. Per period profits are given by:

$$\pi_{it} = D_{it}\left[A_{it} x_{it}^{\theta}\right]^{1-1/\eta_{it}} - \omega_{it} x_{it} - c_{it}^{f},$$

where $\omega_{it}$ is the idiosyncratic input price and $c_{it}^{f}$ is an idiosyncratic fixed cost of operating every period.

In settings with firm heterogeneity as described here, canonical models of industry dynamics (e.g., Jovanovic, 1982; Hopenhayn, 1992; Ericson and Pakes, 1995) also typically add the assumption that potential entrants face entry barriers. Such potential entrants are assumed not to know their market fundamentals prior to entry, pay an entry fee and obtain their first draw of their market fundamentals from a joint distribution. The market fundamentals are assumed to evolve stochastically over time and, consistent with findings in the empirical literature, are assumed to be highly persistent processes.

Industry equilibrium in this setting has a number of interesting properties. First, the curvature of the profit function either through decreasing returns ($\theta < 1$) or through downward sloping demand will support dispersion in physical productivity in equilibrium. We denote physical productivity as *TFPQ*, and in terms of the notation above it is given by $A_{it}$. While

[6] Within-plant productivity is found to increase after trade opening by Levinsohn (1993) for Turkey; Harrison (1994) for Cote d'Ivoire; Tybout and Westbrook (1995) for Mexico; Pavcnik (2002) for Chile; Trefler (2004) for Canada; Topalova (2004) for India; Fernandes (2007) for Colombia; Schor (2004) for Brazil; and Hay (2001) also for Brazil.

[7] In our data, the unit of observation is the plant. Though some of the plant-level heterogeneity we model may reflect firm effects (e.g., demand effects or distortions from credit market imperfections), a multi-plant firm is still likely to try to maximize profits at each plant. Moreover, exploring multi- vs. single-plant differences is complicated by the fact that the decision of becoming a multi-plant firm is itself endogeneous.

some low productivity firms will survive, they will be smaller than the more productive firms so there will be a positive covariance between size as measured by output and productivity as measured by *TFPQ*. The fixed cost of operations will imply that firms with sufficiently low productivity (or other idiosyncratic shocks that lower profitability like low demand or high costs) will exit. The canonical exit decision in this literature can be characterized by[8]:

$$e_{it} = \left\{ \begin{array}{ll} 1 & \text{if } PDV\{\pi(A_{it}, \omega_{it}, D_{it}, \eta_{it}, c^f_{it})\} < 0 \\ 0 & \text{if } PDV\{\pi(A_{it}, \omega_{it}, D_{it}, \eta_{it}, c^f_{it})\} \geqslant 0 \end{array} \right\}.$$

That is, plant $i$ exits if the expected present net discounted value of profits including the fixed cost of operating $c^f_{it}$ is negative. The present discounted value of current and future expected profits is a positive function of productivity shocks, $A_{it}$, demand shocks, $D_{it}$, an inverse function of the demand elasticity, $\eta_{it}$ and input price shocks, $\omega_{it}$.

The impact of trade liberalization on exit, and in turn on aggregate productivity, has been analyzed in this family of models by Melitz (2003). In a version of the model where productivity summarizes all market fundamentals, Melitz predicts a positive impact of trade liberalization on aggregate productivity, through increased exit. As the economy liberalizes, the more productive plants expand by increasing exports, and this drives up the equilibrium wage (more exactly, it drives down the price of goods vis-a-vis the wage). With a higher real wage, only incumbents with productivity above a larger threshold survive. Similarly, Bernard et al. (2003) introduce stochastic plant productivity in a perfect competition Ricardian model where producers from the same country compete to be the sole national supplier to specific destinations. Lower trade barriers bump out low productivity plants due to import competition, while high productivity plants grow into export markets. As outputs and inputs shift from low-productivity exiting plants to high-productivity expanding plants, aggregate productivity increases.[9]

One key feature of these models drives the positive impact of increased exit on aggregate productivity: it is always the lowest productivity businesses that exit the market. However, a recent literature on misallocation and productivity has showed that, in addition to the profit-margin components discussed above, idiosyncratic distortions impact profitability and, in turn, market selection (e.g., Banerjee and Duflo, 2005; Bartelsman et al., forthcoming; Hsieh and Klenow, 2009; and Restuccia and Rogerson, 2008). Thus, in the presence of idiosyncratic distortions, a plant's survival becomes less related to its favorable profit-margin fundamentals, and more to distortions. For instance, heterogeneous trade barriers, such as those that characterized the pre-reform Colombian trade regulation, may allow plants in protected sectors to survive even with relatively low productivity. An interesting implication is that trade liberalization may not only lead to increased competition across-the-board, but also remove idiosyncratic distortions by reducing heterogeneity in protection from trade. In this context, trade liberalization should have the additional effect of enhancing the—initially weak—mechanism that drives low productivity plants out of the market.

Given the possible mechanisms through which trade liberalization can impact market selection, our empirical strategy is based on an enhanced model of exit which includes idiosyncratic market distortions:

$$e_{it} = \begin{cases} 1 & \text{if } PDV\{\pi(A_{it}, \omega_{it}, D_{it}, \eta_{it}, c^f_{it}, \tau_{it})\} < 0, \\ 0 & \text{if } PDV\{\pi(A_{it}, \omega_{it}, D_{it}, \eta_{it}, c^f_{it}, \tau_{it})\} \geqslant 0, \end{cases}$$

where $\tau_{jt}$ represents market distortions from trade barriers for plant $i$, namely tariffs. As noted above, a key insight from the recent literature is that the presence of idiosyncratic distortions across plants, including those due to high tariffs, reduces the marginal effect of fundamentals on the probability of exit. This insight helps guide and interpret our empirical specification of the market selection models presented below. Our core prediction is that sectors with greater tariff reductions have had a larger reduction in market distortions and, accordingly, fundamentals should become incrementally more relevant for market selection in the sectors with greater tariff declines.

Our main focus is on studying a potential change in the slope of the productivity-exit relationship, as illustrated in Fig. 1. An implication from the recent models with idiosyncratic distortions is that a reduction in trade barriers can steepen this slope. The intuition is straightforward: as distortions are reduced, the relative role of market fundamentals like productivity should increase. Previous empirical findings showing increased exit after trade liberalization are consistent with trade reform shifting this curve out (as implied, for example, by the Melitz, 2003, model). An increase in the slope has the potential to enhance the effect of trade reform on aggregate productivity, by increasing the propensity to cut off the lower tail of the productivity distribution. In addition, the recent literature shows (e.g., Bartelsman et al., forthcoming) that reducing the dispersion of idiosyncratic distortions increases the covariance between size and productivity (*TFPQ*) for existing plants, by strengthening the link between market fundamentals and plant scale—since the latter becomes less influenced by distortions. We also address empirically this possibility.

[8] See, e.g., Melitz and Ottaviano (2008) and Foster et al. (2008) for models that yield exit specifications with this full list of market fundamentals (or plant profit-margin components).

[9] Our empirical analysis is closer to Bernard et al. (2003), as we focus on the effects of trade reform on market selection for a given set of fundamentals. By contrast, Melitz (2003) and Melitz and Ottaviano (2008) emphasize how exit will be impacted by trade through changes in fundamentals (i.e., wages and mark-ups, respectively). While the wage channel is likely important, it has been studied in the past in the Colombian context by Goldberg and Pavcnik (2005) and Attanasio et al. (2004), using data better suited for that purpose. In turn, exploring the impact of trade liberalization via changes in mark-ups requires a careful and detailed study of mark-ups that we are conducting in separate work.

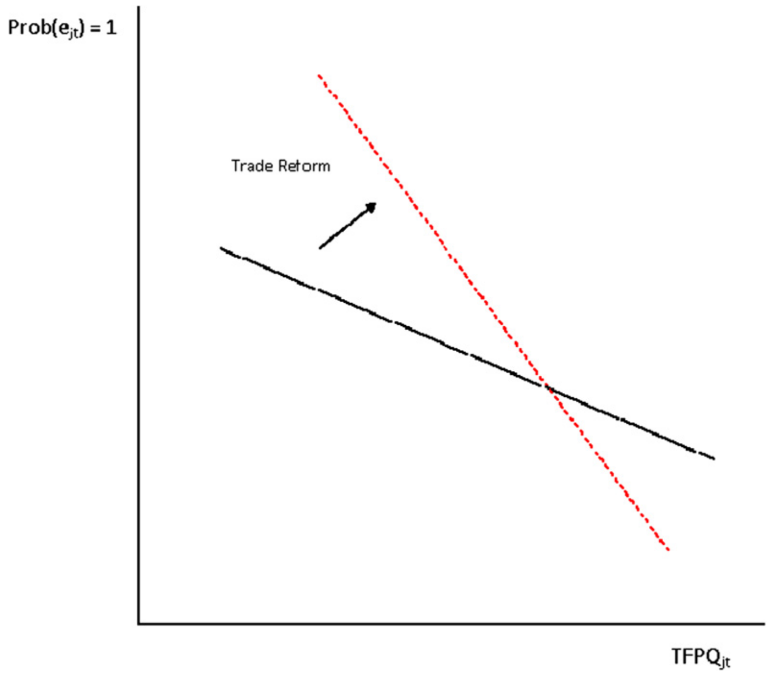


**Fig. 1.** Hypothetical relationship between the probability of exit and productivity.

The channel we seek to identify can be represented by a change in the slope in the productivity-exit relationship as illustrated in Fig. 1. That is, the canonical prediction of selection models is that the probability that a plant exits should be decreasing in productivity (where productivity is not a perfect predictor of survival given the other idiosyncratic determinants of profitability). An implication from the recent models with idiosyncratic market distortions is that the slope of this function will be smaller the greater are idiosyncratic distortions. A reduction in trade barriers can steepen the slope in this context. The intuition is straightforward since, as distortions are reduced, the relative role of market fundamentals like productivity should increase. Trade reform may as well shift out this exit curve (as implied, for example, by the Melitz, 2003, model). It is this shift that other empirical papers, like Baggs (2005) and Gibson and Harris (1996), have examined. However, an increase in the marginal effect has the potential to enhance the effect of trade reform on aggregate productivity since this implies an increased propensity to cut off the lower tail of the productivity distribution.[10]

Idiosyncratic distortions will also impact the allocation of activity across existing firms. That is, the recent literature shows (e.g., Bartelsman et al., forthcoming) that reducing the dispersion of idiosyncratic distortions increases the covariance between size and productivity (*TFPQ*). Decreased dispersion of idiosyncratic distortions implies that the reason that a plant is large will be more due to market fundamentals and less governed by those distortions. We also test this implication empirically.

Other studies have previously attempted to address some of the issues we raise. However, while there are numerous empirical studies which focus on the implied size and productivity covariance and on the determinants of selection, much of that literature uses a measure of revenue productivity *TFPR* (which in terms of the above notation is given by $TFPR = P_{it} A_{it}$). The theoretical predictions described above for market selection and the covariance between size and productivity, on the other hand are based on predictions about the role of *TFPQ* (or $A_{it}$) and not about *TFPR*. In this class of models, $P_{it}$ is endogenous and a function of $A_{it}$ and other demand and cost factors as well. Given this endogeneity, it is not feasible to identify the impact of $A_{it}$ on exit using a measure of *TFPR*. Moreover, it is not feasible to identify the covariance between size and *TFPQ* using a measure of *TFPR*.[11]

[10] Fig. 1 should be interpreted as illustrating the potential role of the interaction (marginal) effect we are exploring "locally". Theoretically and empirically, the relationship between productivity and exit is likely to be highly nonlinear depending on the distributional properties of other shocks to profits. With a normally distributed fixed cost shock and no idiosyncratic distortions, Fig. 1 drawn over the full range of profits would take an inverted S-shape. An across-the-board reduction in tariffs in absence of idiosyncratic distortions flattens the curve at the tails, shifting it out for more intermediate ranges of profits. If, instead, idiosyncratic distortions are present, the S-shape will flatten out as found in Bartelsman et al. (forthcoming). Consider, for example, a correlated distortion environment where the government effectively taxes the most productive and subsidizes the least productive. Then survival and size will depend much less on core productivity (TFPQ) and more on the distortions.

[11] Hsieh and Klenow (2009) using a similar but simpler structure where the only source of heterogeneity in the model is $A_{it}$ show that in the absence of additional frictions or distortions there will be no dispersion in *TFPR* in equilibrium, as marginal revenue products will be equalized to common factor prices. In our setting, there can be dispersion in equilibrium in *TFPR* even in the absence of additional frictions and distortions given the idiosyncratic demand and cost factors. Bartelsman et al. (forthcoming) show that other frictions can also contribute to dispersion in the absence of distortions.

It is useful to note that it is inherently difficult to sign the direction of the bias in using *TFPR* relative to *TFPQ*. The reason is there are effects working in opposite directions. First, $P_{it}$ will be inversely correlated with $A_{it}$ (*TFPQ*) as plants that are more productive will have lower marginal costs and move down their demand curves charging lower prices. This effect will tend to mitigate the impact of *TFPR* on selection as well as lower the covariance of *TFPR* with size. At the same time, $P_{it}$ will be positively related to demand shocks, $D_{it}$, so that high prices can also signal a product with high demand and in turn high profitability. This effect will tend to enhance the impact of *TFPR* on selection as well increase the covariance of *TFPR* with size. Which of these opposing effects on the impact of *TFPQ* as measured by *TFPR* dominates, and how profound the resulting bias is, are empirical questions.[12] Motivated by those questions, we explore how our results change when we use the less preferred (but more commonly available) measure of *TFPR*.[13] Examining differences between *TFPQ* and *TFPR* is of interest beyond the specific context of the effect of reforms. Researchers have long used measures of *TFPR* as imperfect proxies for *TFPQ*. Just how imperfect these proxies are is still open for question.

## 3. Data

To estimate the impact of market fundamentals on exit as trade opens, we require information on tariffs and on plant characteristics, including productivity, demand shocks, demand elasticities, and input prices. Also, to control for other ongoing reforms that may have coincided with trade reforms, we require a measure of other regulations.

We use data for 1982 to 1998 from the Colombian Annual Manufacturing Survey (AMS), an unbalanced panel that registers information on all manufacturing establishments with 10 or more employees, or with production over a certain level. Given that these requirements are satisfied, a plant is then included in our sample in a given year if it reports positive production for that year. The AMS includes information on: the value of production, number of employees, value of materials used, physical units of energy demanded, purchases of capital, as well as the quantities and unit values of each product it manufactures and of each material it uses. We construct the stock of capital for a firm using perpetual inventory methods. Since the AMS does not contain information on hours per worker, we construct a measure of hours at the sector level, using information on wages per sector from the Monthly Manufacturing Survey, and on total payroll aggregated at the sector level from the plant-level information in the AMS (so that plant-level labor hours are obtained by multiplying plant-level employment by a sector-level measure of average hours per worker). For greater detail on the construction of these variables, see Eslava et al. (2004). The data we use identifies the 4-digit sector to which the plant belongs using ISIC revision 2 codes.

A unique feature of the AMS is the existence of plant-level prices for each product produced by the plant and each material used by the plant (at a level of disaggregation comparable to the 6-digit level of the Harmonized System). Using this information, we calculate plant-level price indices for inputs and outputs. To construct a plant-level price index for materials, we first calculate weighted averages of the annual price changes of all individual materials used by the plant,[14] where the weight assigned to each input corresponds to the average share (over the whole period) of that input in the total value of materials used by the plant.[15] Plant-level price indices are then generated recursively from these plant-level price changes, where we set 1982 as the base year.[16] A similar method is used to construct output price indices.

We use plant-level output prices to construct physical quantities of output, which are measured as the nominal output deflated by the plant-level price index. Similarly, we construct physical quantities of materials used as the nominal value of these materials deflated by the plant-level materials price index. Physical quantities of energy usage are directly reported at the plant level.

Table 1 presents descriptive statistics of the quantity and price variables just described.[17] The price and quantity variables are expressed in logs. We restrict our sample to plants in three-digit sectors with more than 30 establishments in the

[12] Idiosyncratic distortions will also impact the dispersion of plant-level prices.

[13] In the absence of plant-level prices for Belgium, De Loecker (2011) introduces a demand system within a production function framework to correct for unobserved prices and finds that the impact of trade on productivity is 50% lower than when standard revenue-based measures of productivity are used. The availability of plant-level prices in the Colombian context allows us to re-examine that question imposing much less structure on the demand side.

[14] Since some large outliers appear, we trim the 1% percent tails of the distribution of plant-level price changes. In addition, given that the inflation rate in Colombia has hovered around 18% during the period, we choose to drop observations that show reductions of prices beyond 50% in absolute value or increases in prices beyond 200%.

[15] We have considered an alternative Divisia index approach where the weight for a product is the average of the product share in the current and prior year. We have found the basic properties of our plant-level fundamentals have similar properties but also we have found this yields substantially more dispersion in plant-level prices and accordingly in TFPQ. In addition, the implied estimates of industry-level price dynamics match the published totals less well than those implied by our approach. Our evaluation is that the year-by-year estimates of product mix are noisy and we have taken the conservative approach of using the time invariant average share.

[16] Given the recursive method used to construct the price indices and the fact that we do not have plant-level information for material prices for the years before plants enter the sample, we replace missing values with the average material price in the plant's sector, location, and year. When the information is not available by location, we impute the national average in the sector for that year. This imputation assumes that the plant that is about to enter would have had a similar product mix as existing plants in the same sector–location–year.

[17] The descriptive statistics capture both within industry as well as between industry variation. In the empirical analysis, we always control for industry effects, so we focus our attention on within industry variation (across plants and across time) in our estimation. We have generated a version of Table 1 that removes industry effects and find very similar patterns, suggesting that much of the between plant variation in outputs, inputs and prices reflects within industry variation.

**Table 1**
Descriptive statistics.

| Variable | Pool data (1) | Within 4-digit sector (2) |
|---|---|---|
| Output | 10.71 | 11.03 |
| | (1.75) | (1.54) |
| Capital | 8.43 | 8.78 |
| | (2.09) | (1.89) |
| Labor | 10.98 | 11.13 |
| | (1.16) | (1.09) |
| Energy | 11.44 | 11.72. |
| | (1.89) | (1.62) |
| Materials | 9.92 | 10.20 |
| | (1.87) | (1.63) |
| Output prices | −0.11 | −0.15 |
| | (0.58) | (0.53) |
| Energy prices | 0.37 | 0.37 |
| | (0.49) | (0.48) |
| Material prices | −0.03 | −0.07 |
| | (0.46) | (0.41) |
| Herfindahl index | 0.18 | 0.18 |
| | (0.16) | (0.00) |
| Entry rate | 0.07 | 0.06 |
| | (0.25) | (0.25) |
| Exit rate | 0.08 | 0.07 |
| | (0.27) | (0.27) |
| *N* | 85,203 | 85,203 |

*Notes*: This table reports means and standard deviations of the log of quantities and of log price indices deviated from yearly log producer price indices. Column (1) reports these statistics for the pooled data, while column (2) reports statistics calculated within 4-digit sectors. To calculate the latter we regress each variable against 4-digit sector dummies. The reported mean is the average of the estimated sector effects, while the reported standard deviation is the standard deviation of the regression residuals. The entry (exit) rate is the number of entering (exiting) plants divided by total observations. An entering plant in $t$ is one that reported positive nominal production in $t$ but not in $t-1$, while a plant that exits in $t$ is one that reported positive nominal production in $t$ but not in $t+1$.

average year, since we make use of within-sector variation in our analysis below.[18] It is worth highlighting that there is high variability even within sectors narrowly defined, as reflected by the fact that standard deviations are similar before and after extracting 4-digit effects. Table 1 also shows entry and exit rates. A plant is classified as entering in $t$ if it exists in our sample in year $t$ but not in $t-1$. Similarly, the plant exits in $t$ if it exists in the sample in $t$ but not in $t+1$. Note that Table 1 reports entry and exit rates of 7% and 8% respectively, somewhat lower than those reported for developed countries (Davis et al., 1996). These lower entry and exit rates for Colombia are consistent with the perception that developing economies are subject to greater rigidities than more developed countries (see, e.g., Tybout, 2000). It should be noted, however, that censoring in our data (at 10 employees) and in manufacturing surveys for other countries (at different cutoffs) makes this comparison imprecise. Censoring also implies that a plant identified as exiting in our sample could be one that contracted below the 10-employee cutoff. As in most studies of plant exit, our statements about exit should thus be interpreted in a wider sense as referring to true exit or contraction to the micro-establishment level.

Data on effective tariffs at the product level come from the National Planning Department. Products are assigned their respective 4-digit ISIC code in the database, so we construct effective tariffs at the four-digit level by averaging effective tariffs across products in a given sector. The only other study of the impact of trade liberalization on productivity with a similar level of disaggregation of tariffs is that by Trefler (2004). Having effective tariffs at this high level of disaggregation allows us to still control for sector effects in our estimation, using 4-digit sector dummies which may capture other factors affecting exits. On the other hand, using sector-level rather than plant-level tariffs reduces concerns about tariffs being influenced by individual firms, especially since we limit our analysis to 3-digit sectors with more than 30 establishments in the average year. In addition, below we discuss robustness checks which address potential concerns about the endogeneity of tariffs.

To control for reforms other than trade, we use the indices on market institutions produced by Lora (2001) which measure market reform in each of five areas: labor regulation, financial sector regulation, trade openness, privatization and taxation.[19] We scale the indices for the different areas to $[0,1]$, where 0 is the year of greatest rigidities and 1 the year

[18] We also eliminate a 4-digit sector for which there is a single plant and that plant is not present in each year. This is because we include four-digit sector effects in some of our estimations.

[19] For descriptions and analyses of the labor market reform, the FDI reform and the payroll tax reform see Kugler (2005, 2006) and Kugler and Kugler (2009), respectively.

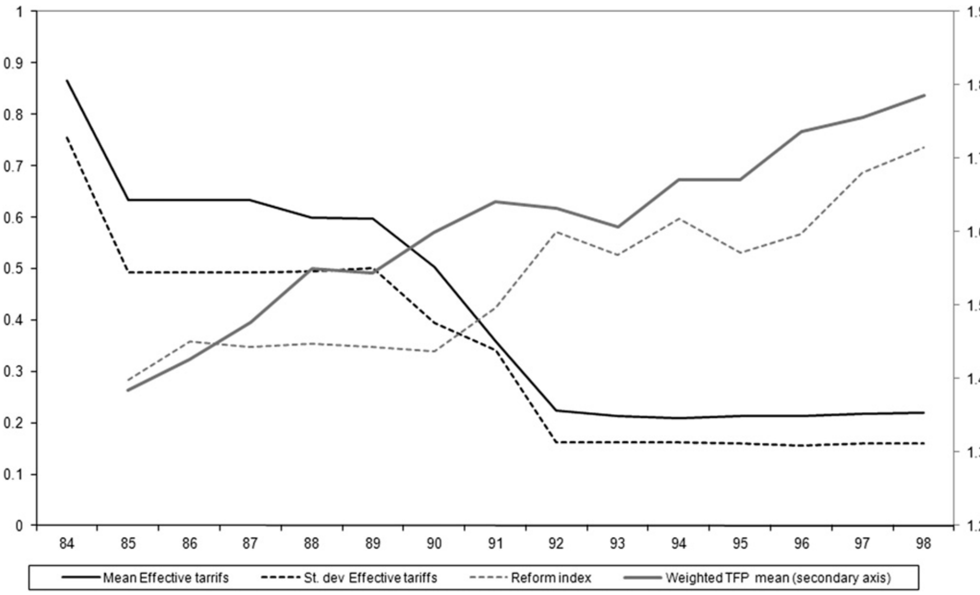


**Fig. 2.** Effective tariffs, reform index, and aggregate TFP, 1984–1998.

of least rigidities in the period. We then average the individual indices, except the trade reform index, to obtain an overall index of reform other than trade.

Fig. 2 illustrates the evolution of tariffs and of the overall reform index. There was a drastic drop in average effective tariffs and in the dispersion of effective tariffs between 1990 and 1992. Average pre-1992 effective tariffs were around 76%, falling to 26.6% in 1992, and averaging 30% in the 1992–1998 period. Even more interesting, the standard deviation of tariffs fell to less than half its pre-92 level: from 0.39 in 1984–1991 to 0.15 in 1992–1998. As Fig. 2 illustrates, this change is concentrated in 1990–1992. It is still worth noticing that, though the dispersion of tariffs fell substantially during the early 1990s, a standard deviation of 0.15 in tariffs is still a substantial level of dispersion. Fig. 2 also shows that the index of other reforms increased at the same time that tariffs were being reduced. This highlights the importance of controlling for other reforms in our estimation.

Fig. 2 also shows an index of manufacturing TFP over our sample period (the index is based on an output-weighted average of the plant-level TFPQ measure which we describe in the next section). It is apparent that there is substantial increase in this index over our sample, part of this increase occurring in the post-reform period—after an initial period of slower growth during the reform years. In particular, manufacturing TFP rose about 14 log points from 1992 to 1998.

### *3.1. Estimation of productivity and demand shocks*

We begin by estimating production and demand functions at the plant level, to obtain measures of TFPQ, demand shifters and the elasticity of demand. Following Eslava et al. (2004), our TFPQ estimates are constructed using factor elasticities estimated using downstream industry demand to instrument inputs, while our plant-level demand estimation uses TFPQ as an instrument. We also construct a measure of physical productivity using cost shares in estimating factor elasticities, and use it in a robustness check of our baseline selection results. More generally, our TFPQ measure is highly correlated with TFP measures calculated using different estimates of factor elasticities.[20] In addition, our demand estimation here allows us to construct a mark-up measure.

#### *3.1.1. Total factor productivity*

We estimate total factor productivity for plant $i$ in year $t$ as the residual from a production function:

$$Y_{it} = K_{it}^{\alpha}(L_{it}H_{it})^{\beta}E_{it}^{\gamma}M_{it}^{\phi}V_{it},$$

[20] Estimating factor elasticities as cost shares, or via OLS estimation of the production function, yields TFP measures that exhibit correlation coefficients of close to 0.9 with our baseline TFP measure. These coefficients are shown in the Web Appendix. In addition, a robustness section below shows that main results are robust to using alternative estimates of factor elasticities. In our earlier work, we have also explored semi-parametric methods to estimate the production function (e.g. Olley and Pakes, 1996), with resulting TFP measures that are highly correlated with the our baseline measure. However, these methods are less suitable for settings were demand shocks and productivity shocks are separately identified, as is the case in this paper (Foster et al., 2008). Robustness in the distribution of plant-level TFP to alternative estimation methods has been also found by Van Biesebroeck (2008).

**Table 2**
Descriptive statistics for different measures of TFP.

| TFP measure | Standard deviation | Correlation coefficients matrix | | | | |
|---|---|---|---|---|---|---|
| | | TFPQ (1) | TFPR (2) | TFPQC (3) | TFPQO (4) | RP1 (5) |
| TFPQ | 0.7668 | 1 | 0.69 | 0.90 | 0.86 | −0.65 |
| TFP deflating output and materials with sector-level prices (TFPR) | 0.6079 | | 1 | 0.53 | 0.40 | −0.00 |
| TFP with factor elasticities equal to cost shares (TFPQC) | 0.7657 | | | 1 | 0.86 | −0.64 |
| TFP with factor elasticities from OLS (TFPQO) | 0.6620 | | | | 1 | −0.72 |
| Output prices relative to PPI (RP1) | 0.5604 | | | | | 1 |
| *N* | | 85,203 | 85,203 | 85,203 | 85,203 | 85,203 |

*Notes*: This table reports standard deviations and correlation coefficients for different measures of TFP and for the plant-level output prices. All correlations and standard deviations are calculated within 3-digit sectors. We report here simple means of those statistics across sectors. TFQ, TFPQC and TFPQO are estimated using plant-level deflators for output and materials, while sector-level deflators are used for TFPR. Factor elasticities used to estimate TFPQ and TFPR come from a 2SLS estimation of the production function. Corresponding elasticities for TFPQO are estimated by OLS, while those for TFPQC are calculated as cost shares at the 3-digit sector level. RP1 is the relative output price reported in Table 1.

where $Y_{it}$ is output, $K_{it}$ is capital, $L_{it}$ is total employment, $H_{it}$ are hours per worker, $E_{it}$ is energy consumption, $M_{it}$ are materials, and $V_{it}$ is a productivity shock.

Our total factor productivity measure is estimated as:

$$TFPQ_{it} = \log Y_{it} - \widehat{\alpha} \log K_{it} - \widehat{\beta}(\log L_{it} + \log H_{it}) - \widehat{\gamma} \log E_{it} - \widehat{\phi} \log M_{it}, \tag{1}$$

where $\widehat{\alpha}$, $\widehat{\beta}$, $\widehat{\gamma}$, and $\widehat{\phi}$ are the estimated factor elasticities for capital, labor hours, energy, and materials. Since productivity shocks are likely to be correlated with inputs, we rely on IV estimates, where the instruments are downstream industry demand shifters (motivated by the approach of Syverson, 2004), input prices, and government spending which are likely correlated with input but uncorrelated with productivity shocks. A more detailed description of this estimation and its results can be found in Eslava et al. (2004).[21] We note that all of our productivity measures are log based, as in Eq. (1).

Table 2 presents summary statistics for our TFP measure estimated with instrumental variables (labeled TFPQ), and compares it to prices and with a measure of TFPR.[22] The TFPQ labeling is meant to emphasize the fact that we deflate output and inputs with plant-level prices, therefore isolating physical efficiency in this measure. All statistics in Table 2 are computed at the three-digit level, and reported for the average sector.

Table 2 shows some interesting patterns that we exploit in our analysis below. First, the table shows considerable dispersion in plant-level prices and TFP within sectors, consistent with the association between price and productivity dispersion and frictions pointed out in recent literature. Second, Table 2 shows that TFPQ is inversely correlated with plant-level prices. This is consistent with more productive plants or industries having lower marginal costs and setting lower prices when faced with downward sloping demand curves.[23] We exploit this inverse relationship to estimate demand elasticities and demand shocks in the next section. This finding is also useful to provide insights as to the underlying sources and interpretations of price variation. Price dispersion is consistent with product differentiation, which may reflect horizontal or vertical differentiation. As such, some of the price variation may reflect product quality variation. If high productivity plants are also high quality plants, and prices reflect quality, a positive correlation between prices and productivity would result. The fact that this correlation is actually negative (a finding that holds for every 3-digit sector) suggests that quality is not an overwhelmingly important source of noise for our focus on physical efficiency.

Table 2 also illustrates one dimension in which being able to measure plant-level prices and physical efficiency is important. TFPR is the standard measure of revenue productivity, often used in the literature in the absence of plant-level prices. TFPR is calculated by using as the output measure plant-level revenue divided by sector-level price indices and using as the material measure plant-level expenditures on material divided by sector-level materials price indices. Although TFPQ and TFPR are positively related, the correlation coefficient is only 0.68. Moreover, TFPR is essentially uncorrelated with plant-level prices. Indeed, the relationship between prices and productivity, which we exploit in our data to identify demand elasticities and shocks, disappears when sector-level deflators are used. The reason for this is straightforward: variation in TFPR directly reflects the variation in prices, and the resulting positive correlation with plant-level prices offsets the negative correlation between prices and physical productivity (TFPQ).[24]

[21] Although the sample differs slightly because we drop observations from sectors with few establishments, the estimated factor elasticities we use here are the same as those in Eslava et al. (2004) up to the second decimal place. We note that our approach builds on Syverson (2004) and Shea (1993, 1997) in using sector downstream demand to instrument factor use in the plant, but also extends it with the use of input prices. The downstream demand indicators are generated by using the input–output matrix. Sector downstream demand is in principle exogenous to the plant, as the plant is small with respect to its own sector. Additionally, only downstream sectors that represent a small share of sales for the plant's sector are considered in the estimation of the factor elasticities in the manner suggested by Shea.

[22] The Web Appendix for this paper further shows correlations of our measure of TFPQ with different alternative measures of productivity and prices.

[23] To address concerns that this inverse correlation may be driven by division bias (plant-level prices appear in the denominator when estimating physical output used to calculate TFPQ) we have also estimated the correlation between lagged TFPQ and current prices. This correlation is −0.59.

[24] We further explore the potential effect of lacking access to plant-level prices by estimating our exit equations alternatively with the traditionally available measures of fundamentals and with the improved measures we can obtain using plant-level prices.

**Table 3**
Demand estimation. Instrument: TFP from 2SLS estimation of the production function.

| Dependent variable: output | OLS<br>(1) | 2SLS<br>(2) |
|---|---|---|
| Relative price | −0.7982*** | −2.4199*** |
| | (0.0167) | (0.1216) |
| | | [0.2355] |
| Relative price × Herfindahl | −0.4399*** | 2.0666*** |
| | (0.1399) | (0.7204) |
| | | [0.3330] |
| Sector effects | 4-digit | 4-digit |
| $N$ | 72,148 | 72,148 |

*Notes*: This table reports results from estimating demand functions. Robust standard errors are in parentheses. First stage $R^2$s in square brackets. The Herfindahl index is calculated at the 4-digit level. The 2SLS regression in column (2) instruments price with innovations to TFP (from an AR(1) model).

* Significant at 10%; ** Significant at 5%; *** Significant at 1%.

### *3.1.2. Demand estimation*

While productivity is likely to be one of the crucial components of profitability, as discussed in Section 2, other components are also probably important determinants of profitability and survival. For example, even if plants are highly productive, they may be forced to exit the market if faced with large negative idiosyncratic demand shocks. Another important determinant of exits is likely to be the degree of market power of a producer, which empirically can be captured by the mark-up or the inverse of the demand elasticity. In this section, we describe how we estimate both the demand shocks as well as demand elasticities.

Our demand shock and demand elasticity measures are estimated from a demand equation, which in its simplest form may be written (in logs) as:

$$\log Y_{it} = \eta_s \times \log P_{it} + \log D_{it}.$$

When estimating this demand function, we allow the elasticity of demand to vary by four-digit industry, as a function of concentration in the sector. We also control for four-digit industry effects. We thus estimate

$$\log Y_{ist} = \alpha_s + \alpha_0 \times \log P_{it} + \alpha_1 \times \log P_{it} \times HI_s + \log D_{ist}, \tag{2}$$

where $s$ is the four-digit sector in which plant $i$ is located, and $HI_S$ is a Herfindahl index calculated at the four-digit sector level, based on output shares. We initially construct this Herfindahl index by year for each sector, and then average over years obtaining a measure of concentration that varies only by sector. Descriptive statistics for this index are presented in Table 1 for the pooled sample. The Herfindahl index for the average plant in our sample is 0.18.

In this case, the demand shock is the residual from estimating the above equation, while the demand elasticity for four-digit sector $s$ to which plant $i$ belongs is given by:

$$\widehat{\eta}_s = \widehat{\alpha}_0 + \widehat{\alpha}_1 \times HI_s. \tag{3}$$

Using OLS to estimate the demand function is likely to generate an upwardly biased estimate of demand elasticities because demand shocks are positively correlated to both output and prices, so that $\widehat{\eta}_s$ will be smaller in absolute value than the true $\eta_s$. To eliminate the upward bias in our estimates of demand elasticities, we use productivity as an instrument for $P_{it}$ since productivity is negatively correlated with prices but unlikely to be correlated with demand shocks (Eslava et al., 2004).[25] A subtle issue is that while innovations to demand and productivity are likely uncorrelated, the level of demand and productivity may be correlated due to selection. That is, high demand shock plants in prior periods are more likely to have survived and survival itself will be correlated with TFPQ. To avoid such concerns, we use the innovation to TFPQ as the instrument rather than TFPQ itself. We measure innovations to TFPQ as residuals from estimating an AR(1) process on TFPQ.

Columns (1) and (2) of Table 3 report the OLS and IV results from estimating demand equation (2). Robust standard errors are presented in parentheses.[26] OLS results presented in column (1) yield an estimated average elasticity of −0.88.

[25] We discuss below the role of product quality variation which is potentially problematic for this identifying assumption. We also acknowledge that the macro literature pays considerable attention to measured cyclical fluctuations in TFP being associated with unmeasured changes in factor utilization (see, e.g., Basu and Fernald, 2001). As such, at the aggregate level, the assumption of measured TFP and aggregate demand shocks being uncorrelated may be problematic. However, we are mostly exploiting cross-sectional variation in plant-level TFP with the variance of idiosyncratic shocks an order of magnitude larger than any aggregate shock. Moreover, the idiosyncratic TFP and demand shocks we estimate are highly persistent suggesting that issues about cyclical factor utilization are dwarfed by the highly persistent idiosyncratic shocks (thus, inducing relatively little idiosyncratic variation in unmeasured factor utilization). Also, to the extent that energy usage proxies for capacity utilization, we would be taking the utilization factor out of our TFP measure, addressing another possible source of concern about the validity of our assumption that TFPQ is uncorrelated with demand.

[26] Woolridge (2002) notes that in models with unobserved heterogeneity at the group level assumptions need to be made about the form of this heterogeneity. One could assume that the unobserved heterogeneity is not correlated with the RHS variables and then use random effect estimators and/or

Meanwhile, IV results in column (2), which use innovations to TFPQ as an instrument, show a much higher average elasticity of −2.05. Moreover, this elasticity is higher for less concentrated sectors, as should be expected. Our point estimates suggest that an increase of one standard deviation in the Herfindahl index for the four-digit sector yields a reduction of 0.35 in the elasticity of demand. In what follows, we use the estimates of demand shocks and elasticities from column (2) of Table 3 in our analysis of the impact of market fundamentals on plant exit. Since our elasticity of demand varies by four-digit sector we are unable to separate its effect on exit from general sector effects, but we will be able to study whether the impact of mark-ups varies with the trade reform.

## 4. Market fundamentals, trade and plant exit

As discussed in Section 2, a plant ceases operations if its net present discounted value of profits (inclusive of fixed costs of operating) is negative. Assuming that the fixed cost, $c^f_{it}$, is drawn from a normal distribution, the canonical model of a plant's probability of exit can be specified as a probit model, where the probability of exit between $t$ and $t+1$ is a function of measures of market fundamentals in period $t-1$. In our particular case, such a baseline specification would take the following form[27]:

$$\Pr(e_{it}=1)=\Pr\big(\kappa_s+\theta_1 \mathit{TFPQ}_{it-1}+P'_{Iit-1}\Theta_2+\theta_3 D_{it-1}\leqslant c^f_{it}\big), \tag{4}$$

where $e_{it}$ takes the value of 1 if the plant $i$ (in sector $s$) exits between periods $t$ and $t+1$; $\kappa_s$ are 4-digit industry effects; $\mathit{TFPQ}_{it-1}$ measures productivity in period $t-1$, $P_{Iit-1}$ is a vector of energy and materials prices in period $t-1$; $D_{it-1}$ is a demand shifter in period $t-1$; and $c^f_{it}$ is an i.i.d. normally distributed error term. This empirical specification uses fundamentals dated at time $t-1$ to predict exit from $t$ to $t+1$ given possible incomplete measurement and endogeneity issues in period $t$ (the period just prior to exit). Our data are calendar year data but there may be mid-year exits which yield measurement error in fundamentals for part year plants. Moreover, if the process of exit itself impacts fundamentals as the plant shuts down, there is a problem of reverse causality. The use of period $t-1$ information mitigates both of these concerns. The 4-digit sector effects would capture differential demand elasticities, as well as other fixed factors varying across 4-digit sectors.

The model we estimate and focus on expands this baseline model to incorporate and in turn assess the impact of trade reform on market selection.[28] In particular, we add the sector-level tariffs as well as interactions of these with physical productivity and other market fundamentals to the baseline probit specification. As discussed above, the interaction between tariffs and productivity is a focal point of this paper. We also include an index for other reforms to make sure that tariffs do not pick additional institutional changes that were contemporaneous to the trade reform. We estimate the following probit model:

$$\begin{aligned}\Pr(e_{it})=\Pr\big(&\kappa_s+\theta_1 \mathit{TFPQ}_{it-1}+P'_{Iit-1}\Theta_2+\theta_3 D_{it-1}+\theta_5\tau_{st}+\theta_{5,1}\mathit{TFPQ}_{it-1}\times\tau_{st}+(P_{Iit-1}\times\tau_{st})'\Theta_{5,2}\\&+\theta_{5,3}D_{it-1}\times\tau_{st}+\theta_{5,4}\eta_s\times\tau_{st}+\theta_6 R_t+\theta_{6,1}\mathit{TFPQ}_{it-1}\times R_t+\big(P_{Iit-1}\times R'_t\big)\Theta_{6,2}+\theta_{6,3}D_{it-1}\times R_t\\&+\theta_{6,4}\eta_s\times R_t+\theta_4 \mathit{GDP}_t\leqslant u_{it}\big),\end{aligned} \tag{5}$$

where $e_{it}$, $\kappa_s$, $\mathit{TFPQ}_{it-1}$, $P_{Iit-1}$, and $D_{it-1}$, are defined as in Eq. (4). $\tau_{st}$ is the tariff in sector $s$ in year $t$; $R_t$ stands for the index of reforms other than trade at time $t$; and $\mathit{GDP}_t$ is the growth of aggregate gross domestic product in year $t$. Our measure of $\tau_{st}$ is the average effective tariff faced by plants in a given 4-digit sector in year $t$. Note that we include interactions of the indices of reforms not only with these fundamentals, but also with $\eta_s$, the sector-level elasticity of demand, even though we cannot include this elasticity simply as a control given the inclusion of 4-digit sector effects. Furthermore, even though our index of other reforms only varies over time, the inclusion of an interaction between this index and the demand elasticity effectively allows the effect of other reforms to vary across 4-digit sectors, in a way that depends on a relevant dimension (market power). The inclusion of GDP growth in Eq. (5) is meant to capture any other aggregate effects on exit.[29]

We regard this flexible specification with interactions as consistent with the discussion in Section 2, in particular with the literature that has pointed at idiosyncratic policies as distortions to the canonical relationship between plant-level market fundamentals and exit. In particular, this specification permits us to test and explore our primary hypothesis—that is, that

clustered standard error corrections as appropriate. He notes that permitting fixed effects that are potentially correlated with RHS variables is more robust than these alternatives but also notes that robust standard error estimators are required. It is this latter approach that we use throughout this analysis.

[27] To justify a probit we require that there be some unobserved heterogeneity to account for the variation in the data on plant exit. Variation in the fixed cost of operating each period is an obvious candidate, though not the only one. For ease of exposition, we refer to this stochastic unobserved heterogeneity as a stochastic fixed cost.

[28] Results of estimating the baseline model (4) are shown in the Web Appendix, Tables WA3 to WA6. The last of these tables estimates the model as a linear probability model, and takes advantage of this setting to control for plant-level fixed effects. The results of the fixed effects estimation are quite similar to those of the probit estimation without fixed effects.

[29] We use the approach of controlling for both GDP growth and other reforms, rather than controlling for time dummies because an important part of the trade liberalization in the period occurred at the aggregate level. However, we do examine the robustness of our results to including time effects rather than GDP growth, and we discuss these results below.

**Table 4**
Descriptive statistics of determinants of survival.

| Variable | Pool data<br>(1) | Within 4-digit sector<br>(2) |
|---|---|---|
| Lagged TFPQ | 1.1732 | 1.2274 |
| | (0.7785) | (0.7151) |
| Lagged TFPR | 1.3672 | 1.4384 |
| | (0.6692) | (0.5737) |
| Lagged energy prices | 0.4127 | 0.4171 |
| | (0.4886) | (0.4823) |
| Lagged materials prices | −0.0175 | −0.0606 |
| | (0.4570) | (0.4054) |
| Lagged sector energy prices | 0.3576 | 0.3297 |
| | (0.2415) | (0.2087) |
| Lagged sector material prices | −0.0294 | −0.0295 |
| | (0.2497) | (0.1439) |
| Lagged demand shock | 11.3550 | 11.3698 |
| | (1.6294) | (1.6287) |
| Lagged demand elasticity | −2.2422 | −2.0426 |
| | (0.1672) | (0.0000) |
| Reforms other than trade | 0.4508 | 0.4589 |
| | (0.1220) | (0.1201) |
| Effective tariffs | 0.5589 | 0.4625 |
| | (0.3850) | (0.2820) |
| GDP growth | 0.0408 | 0.0408 |
| | (0.0121) | (0.0121) |
| *N* | 58,290 | 58,290 |

*Notes*: This table reports means and standard deviations of the variables used to estimate exit probabilities. Column (1) reports these statistics for the pooled data, while column (2) reports statistics calculated within 4-digit sectors. To calculate the latter we regress each variable against 4-digit sector dummies. The reported mean is the average of the estimated sector effects, while the reported standard deviation is the standard deviation of the regression residuals. Demand shocks and demand elasticities come from the estimation reported in column (2) of Table 3. The index of other reforms is constructed using all components of the Lora Overall Reform Index, except those included in the Trade Index. Each of the sub-components of Lora's index has been re-scaled to be 0 in the year of less liberalization in Colombia and 1 in the year of most liberalization in Colombia. Effective tariffs are available at the four-digit level, calculated from data by the National Planning Department. The sample is restricted to observations that enter the regressions in Tables 5 and 6.

plants in sectors with a greater reduction in tariffs will exhibit a more marked decline in market distortions and, in turn, the marginal effect of physical efficiency on exit will increase implying improved market selection. The interaction between TFPQ and tariffs in the above specification is included to test this hypothesis. We note that it is this aspect of our specification (as well as the improved measurement of fundamentals) that is different from most of the literature on trade reform and exit. Most of the literature focuses on the direct effect in tariffs (i.e., the coefficient $\theta_5$) while our focus is $\theta_{5,1}$ which as we will see below is critical for the marginal effect of productivity on exit. We include interactions of tariffs with the other fundamentals to make sure that we properly isolate the potential increased effect of TFPQ from changes in the effects of other plant characteristics associated with trade liberalization. We use effective tariffs, rather than nominal tariffs, to take into account indirect protection from trade given to upstream and downstream industries. We also consider an alternative version of this interacted specification using the TFPR and sector-level input prices instead of our preferred plant-level measures.

Table 4 reports summary statistics for the determinants of exit included in Eq. (4) (except for input prices which are reported in Table 1), as well as for effective tariffs and indices of other reforms, which will be included in an expanded specification. Since the index of other reforms is only available starting in 1985, our estimation period for the exit equations is 1985–1998. Table 4 only considers observations from this period, and that additionally have information on all market fundamentals and measures of reform. These are the observations that later enter the estimation of the exit models.[30] Comparing columns (1) and (2) shows that not much of the variability in each of these variables is lost by soaking up 4-digit sector effects (as we do in our estimations.)

Columns (1)–(3) of Table 5 report results of estimating Eq. (5). Each row of Table 5 reports the marginal effect for the corresponding variable. Given the presence of interaction terms, note that, for example, the marginal effect of productivity in model (5) is given by:

$$\frac{\partial \Pr(e_{ist})}{\partial TFP_{it-1}} = F'\big({X'}_{it}\Theta\big)[\theta_1 + \theta_{5,1}\tau_{st} + \theta_{6,1}R_t], \tag{6}$$

[30] The reduction in the sample considered in Table 4 explains why the average demand elasticity reported here differs slightly from the one mentioned above in the text.

**Table 5**
Determinants of exit probability in a model with reforms and tariffs (marginal effects).

| Regressor | Ef. tariffs at 60% (1) | Ef. tariffs at 20% (2) | Difference (3) | Ef. tariffs at 60% (4) | Ef. tariffs at 20% (5) | Difference (6) |
|---|---|---|---|---|---|---|
| Lagged TFPQ | −0.0160*** | −0.0221*** | 0.0061*** | | | |
| | (0.0015) | (0.0026) | (0.0024) | | | |
| Lagged energy prices | 0.0009 | 0.0042 | −0.0033 | | | |
| | (0.0021) | (0.0033) | (0.0027) | | | |
| Lagged materials prices | 0.0195*** | 0.0326*** | −0.0131*** | | | |
| | (0.0025) | (0.0044) | (0.0038) | | | |
| Lagged demand shock | −0.0227*** | −0.0271*** | 0.0043*** | | | |
| (Column (2) Table 3) | (0.0007) | (0.0013) | (0.0011) | | | |
| Lagged demand elasticity | 0.0137 | 0.0267 | −0.0130 | | | |
| (Column (2) Table 3) | (0.0513) | (0.0439) | (0.0098) | | | |
| Lagged TFPR | | | | −0.0286*** | −0.0312*** | 0.0027 |
| | | | | (0.0021) | (0.0035) | (0.0030) |
| Lagged sector energy prices | | | | 0.0151** | 0.0112 | 0.0039 |
| | | | | (0.0066) | (0.0108) | (0.0086) |
| Lagged sector material prices | | | | 0.0364*** | 0.0496*** | −0.0132 |
| | | | | (0.0120) | (0.0119) | (0.0115) |
| Effective tariffs | −0.0199*** | −0.0223*** | 0.0024* | −0.0155** | −0.0167** | 0.0012 |
| | (0.0056) | (0.0069) | (0.0014) | (0.0066) | (0.0076) | (0.0010) |
| Other reforms index (level and interactions) | Yes | | | Yes | | |
| Sector effects | 4-digit | | | 4-digit | | |
| GDP growth | Yes | | | Yes | | |
| Goodness of fit | Pseudo-R2 = 0.078, Wald chi2 = 1616.39 | | | Pseudo-R2 = 0.037, Wald chi2 = 971.81 | | |
| *N* | 58,290 | | | 58,290 | | |

*Notes*: This table reports marginal effects and robust standard errors from a probit estimation of the probability of exit where exit is 1 for plant $i$ in year $t$ if the plant produced in year $t$ but not in year $t+1$. Robust errors in parentheses. Marginal effects are evaluated at mean values of all variables, except for effective tariffs. In columns (1) and (4) effective tariffs are set at a value of 60%, while in columns (2) and (5) they are set at 20%. Columns (3) and (6) report the difference between effects when tariffs are at 20% and at 60%. Pseudo-R2 is the McFadden Pseudo R2.

* Significant at 10%; ** Significant at 5%; *** Significant at 1%.

where $F'$ is the marginal density for the normal distribution, and $X'_{it}\Theta$ summarizes all covariates and coefficients in (5). Similar expressions characterize the marginal effects of other fundamentals (with the exception of demand elasticities, for which the equivalent of $\theta_1$ in expression (6) will be absent).

Marginal effects reported in Table 5 are calculated at the mean value for all variables, except for tariffs, which are allowed to vary across columns: in column (1) tariffs are set at 60%, while in column (2) they are set at 20%. Since the mean value of tariffs for our full period is 56%, the effects reported in column (1) are close to those obtained when tariffs are set at their mean values. Column (3) of Table 5 reports the difference between the effects in columns (1) and (2), indicating changes in the marginal effect of each fundamental when tariffs fall from 60% to 20%. In this way, we focus on a discrete change in tariffs similar in size to the one that took place in Colombia (Fig. 2).[31]

As expected, we find evidence of market selection in that exit depends on productivity: higher lagged TFPQ is negatively related to the probability of exit. The magnitude of the estimated effects is large compared with the average 8% exit rate: we find that an increase in TFPQ of one standard deviation, holding the other covariates at their means, reduces the probability of exit by close to 1.2 percentage points.[32] We also find plausible effects for other plant-level market fundamentals we control for: positive demand shocks reduce the probability that a plant exits, while higher input prices increase that probability. A one-standard-deviation increase in the demand shock reduces the exit probability by around 2.8 percentage points, while a similar increase in the price of materials increases the probability of exit by close to 1 percentage points. We do not find a significant effect of demand elasticities, once plant-level market fundamentals have been controlled for. Energy prices are also not significant in this specification. We find evidence of a direct impact of tariffs on exit. The results show that the probability of exit increases significantly with a reduction in tariffs. In the next section, we quantify the overall change in the probability of exit from the observed reduction in tariffs in Colombia over our sample period. All of these results are robust to the inclusion of year dummies to control for aggregate shocks instead of GDP growth (see Section 6).

Beyond the direct effect of tariffs on exit, we find that liberalizing trade leads to changes in the role of productivity for market selection: when tariffs fall from 60% to 20% the marginal effect of TFPQ grows significantly (in absolute value).

[31] Given the large changes in tariffs we are evaluating, we follow this approach rather than calculating the cross derivative of the probability of exit with respect to the fundamental and tariffs as suggested by Ai and Norton (2003).

[32] Note that because our exit model is not linear and because one standard deviation changes in the fundamentals are not marginal changes, these effects cannot simply be obtained by multiplying the change in the fundamental by its marginal effect. We obtain them by evaluating the probability of exit when one fundamental is one standard deviation away from its mean and the others are at their means, and calculating the difference between that probability and the probability of exit when all regressors are at their means. Full results from this exercise can be found in the Web Appendix to this paper, Table WA3b.

In particular, the marginal effect of a one-standard-deviation increase in productivity on the probability of exit is −1.1 percentage points if tariffs are at 60%, and −1.5 points if tariffs are at 20%. This is our main result in this section and it is consistent with our initial hypothesis that lifting barriers from trade improves market allocation by increasing the probability that low productivity plants exit, as depicted in Fig. 1. That is, trade liberalization—beyond simply increasing exit—enhances market selection. The remainder of the paper assesses the implications of this finding for aggregate productivity, places it in context, and assesses its robustness.[33]

Before deepening the analysis of the market selection effect just described, it is interesting to note that we also find an enhanced effect of other market fundamentals, in particular the prices of materials, and demand shocks. Also, we should note that the results from estimating this specification are largely robust to including year dummies rather than GDP growth to control for aggregate shocks, as shown in Section 6.

A first question relating the enhanced market selection mechanism found in columns (1)–(3) of Table 5 is whether our ability to measure plant-level prices is important to identify this effect, and more generally to identify the effects of market fundamentals on exit. Columns (4)–(6) of Table 5 show results when we use revenue productivity and sector-level energy and material prices instead of our baseline plant-level measures of market fundamentals. We estimate a significant negative effect of TFPR, in fact with a larger marginal effect than that of TFPQ. This likely reflects the fact that TFPR combines idiosyncratic productivity and demand shocks, both of which have negative effects on the probability of exiting. In particular, a one standard deviation change in TFPR induces a decrease in exit probability of 1.7 percentage points compared to a 1.2 point effect of a one standard deviation change in TFPQ, even though TFPR exhibits less dispersion than TFPQ. The effect of energy prices and materials prices is also enhanced when they are measured at the sector level.

Despite the larger marginal effect of TFPR vis-a-vis TFPQ, we find no statistically significant change in the marginal effect of TFPR related to the reduction in tariffs. The difference in the marginal effect of TFP when moving from 60% to 20% tariffs is not only insignificant from a statistical standpoint when using TFPR, but also much smaller in magnitude than that found when using TFPQ: it amounts to less than 10% of the original effect of TFPR (0.027/0.286) compared with 37.5% of the original marginal effect of TFPQ (0.006/0.016). That is, in the absence of access to plant-level prices we would identify no change in the relationship between market selection and productivity related to the trade liberalization. Similarly, we don't find a significant change in the effect of materials prices when these are measured at the sector level. To understand these results, it is useful to recall that TFPR is a composite measure that will reflect a number of different factors that do not all work in the same direction. The inverse correlation between prices and TFPQ implies that, holding other things equal, TFPR will mitigate the impact of productivity relative to the TFPQ measure. Alternatively, the positive correlation between prices and demand shocks as well as the correlation between prices and the demand elasticity imply that TFPR will also capture other determinants of profitability. Since trade reforms are also likely to affect different components of profitability, using only the TFPR measure makes it difficult to identify the survival of more technologically sophisticated plants after trade opening. It is also interesting to note that the pseudo R-squared falls significantly when using TFPR rather than TFPQ.[34]

The other crucial question about our finding that market selection is enhanced by trade liberalization is related to its implications for aggregate productivity. After all, only a small fraction of plants exit the market each year, so their aggregate impact could be negligible. We examine this question in the following section. We also note that our focus in this part of the paper is on the impact of trade liberalization on market selection for a given evolution of fundamentals at the micro (plant) level. It is possible that trade liberalization impacted this evolution of fundamentals at the micro level directly. We also address within-establishment changes in productivity induced by trade liberalization in the following section, to place our findings relating market selection in context. It would be of interest in future work to examine the impact of trade liberalization on other micro fundamentals such as input prices. While we have not examined this channel directly, our specification takes into account any changes in input prices induced by trade liberalization (or for that matter any other changes in micro fundamentals) since we use the actual micro fundamentals in our empirical analysis.

Before proceeding to the implications of the analysis for aggregate productivity in the next section, it is useful to note that we have conducted a number of robustness checks of the results in Table 5. We discuss these tests in Section 6 below.

## 5. Effects of trade liberalization on productivity

In this section we explore various channels through which reduced tariffs and increased foreign competition may have affected average productivity in the manufacturing sector. Given our focus on plant exit, we first investigate the implications of our findings on improved market selection for average productivity. In addition, we explore whether greater international competition increased productivity by changing the behavior of incumbent establishments. Trade liberalization may yield within-plant increases in productivity through a variety of effects, including incentives to invest in technology in response to increased competition and greater exposure to the world production technology frontier. In addition, reduced distortions can lead to an improvement in the overall allocation of activity. That is, increased competition is likely to move production

[33] Varying the level of the index of other reforms at which marginal effects of fundamentals are evaluated makes no significant difference in these effects (Table WA11 of the Web Appendix). However, this should not be taken as hard evidence that other reforms had no effect on selection. Our ability to identify the effects of other reforms is quite limited by the fact that we have a measure of other reforms that varies only at the aggregate level.

[34] The statistic being reported is the McFadden Pseudo Rsquared. It cannot be interpreted in terms of the fraction of variability of the probability of exit explained by the model, but it does vary between 0 and 1, and larger values of this statistic imply a better fit of the model to the data.

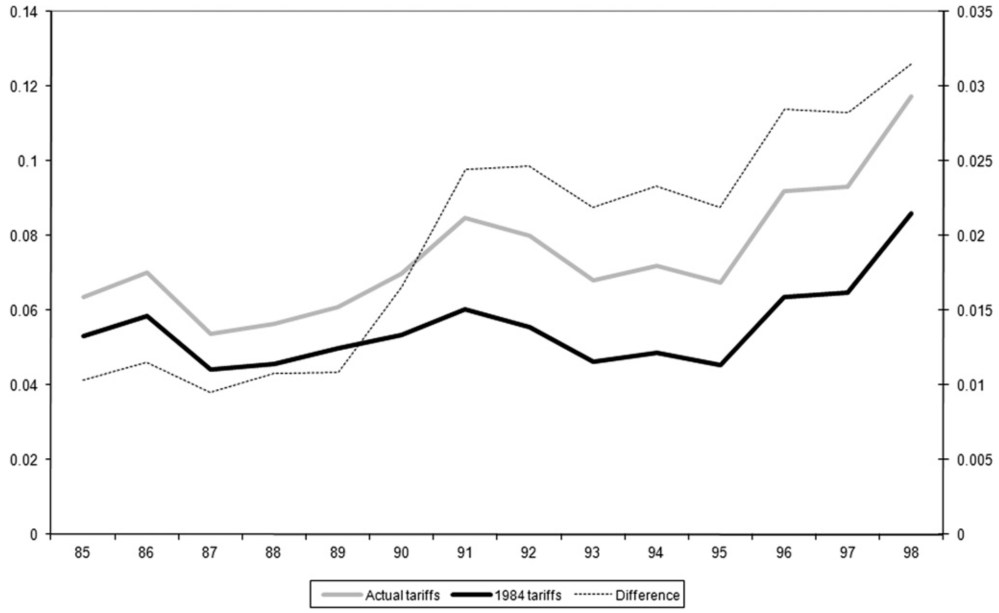


**Fig. 3.** Predicted exit probability: actual tariffs vs. 1984 tariffs.

from low towards high productivity plants, strengthening the correlation between market share and plant-level productivity. As we have noted in the introduction, there are a number of papers that have explored some of these channels empirically (including, Baggs, 2005; Trefler, 2004; Pavcnik, 2002; Head and Ries, 1999; and Gibson and Harris, 1996). Our value added here is that we use this exploration of alternative channels to help put our results on market selection into perspective. In addition, our results are the first to use measures of plant-level physical productivity in this context and one of the few papers to use tariff measures at a fine level of disaggregation.[35]

### 5.1. Trade-induced exits and productivity

The above analysis of exit suggests that trade reform made productivity (and other market fundamentals) more important in determining which plants remain in operation. These results imply that trade liberalization increases the probability that the least productive plants exit. Thus, one may expect enhanced market selection to contribute to increased average productivity. This contribution is likely cumulative since the exit of low productivity plants in a given year implies that market selection in subsequent years will be based on an already improved selection of plants.

As a first illustration of the quantitative implications of enhanced market selection as illustrated by Table 5, we conduct a simple counterfactual using the estimated model of exit (more precisely, the results from columns (1)–(3) of Table 5). We compare the plant-level predicted probability of exit when tariffs take on their actual values in each year to the predicted probability of exit when we fix tariffs at their highest levels, i.e., their 1984 levels, holding all other explanatory variables at their mean values. Fig. 3 shows that the mean predicted probability of exit would have been higher every year with the actual tariffs than if tariffs had stayed at their 1984 levels, with the difference (the dotted line) being particularly acute during the 1990s. The difference between these two predictions is in the 2 to 3 percentage point range during the 1990s—again a large effect relative to the average exit rate of 8% (7% in 1984–1990 and 9% in 1991–1998). These findings are consistent with the predictions of models like those of Melitz (2003) and also consistent with empirical findings in the literature cited above that finds that trade reform increases exit.

This counterfactual is static, in the sense of not following plants over time—beyond using $t-1$ market fundamentals to predict exit in $t$—and as such it likely understates the overall effect on exit by not considering the cumulative effects of reform. Moreover, it does not directly measure the effect of the reform on aggregate productivity. We now undertake a dynamic counterfactual simulation, which accounts for cumulative effects and allows us to quantify the effect of enhanced selection on aggregate productivity. The counterfactual simulates the set of plants predicted by our estimated exit model to survive from one year to the next, given estimated plant fundamentals and given tariffs, and then calculates average TFPQ for that set of plants. To estimate the effect of changes in tariffs on average TFPQ that can be attributed to changes

[35] Trade liberalization can also impact plant performance through increased availability of new inputs, either in terms of new varieties or higher quality. Goldberg et al. (2009) document this on the input side, and Goldberg et al. (2008) on the output side. Kugler and Verhoogen (2009) present evidence consistent with higher quality of imported inputs, while Amiti and Konings (2007) and Halpern et al. (2005) find evidence that the more intensive use of imported inputs due to trade liberalization is associated with higher productivity among manufacturers. While our paper does not analyze these channels directly, our use of effective, rather than nominal, tariffs takes into account improved access to imported inputs.

in the exit process, we carry the simulation of survival under two different tariffs scenarios, while keeping everything else constant. Our tariffs scenarios are the "actual tariffs" and the "1984 tariffs" scenario. Under the actual tariffs scenario, we predict exit using the actual values of tariffs, and then estimate the implied path of average productivity for 1985–1998. Under the 1984 tariffs scenario, we repeat the same exercise but changing tariffs to their 1984 value when predicting exit. We then compare results of the two scenarios to measure the impact of trade reform on average productivity. We report average results over 1000 rounds of this simulation.

Our dynamic simulation can be described in more detail as follows. A first step is to estimate AR(1) processes for each plant-level market fundamental (TFPQ, demand shocks, and input costs). Each of these regressions is estimated using the entire pooled dataset. The AR(1) coefficient as well as the distribution of innovations from each of these regressions are used to project market fundamentals for the different plants across time. (Estimates of the different AR(1) coefficients for different fundamentals are shown in the Web Appendix, Table WA7.) In the next step, we generate a predicted probability of exit for each of the plants present in our sample in 1985, using the estimated probit model of Eq. (5). Our calculation of this prediction feeds into the model the actual value of market fundamentals (TFPQ, demand shocks, input costs, and demand elasticity) for the plant in 1985, the actual value of GDP growth and value of $R_t$—the index of reforms other than trade—and the actual plant sector. The level of tariffs we use in this prediction depends on the scenario we are simulating: our "actual tariffs" scenario uses the actual value of tariffs in the plant's sector in 1985, while our "1984 tariffs" scenario sets those tariffs at their initial, 1984, level. We then use the predicted probabilities of exit to predict whether each plant exits the market or stays at least one additional year, using a random number generator. This is done both for the actual tariffs scenario and for the counterfactual tariffs scenario.

We continue this process recursively in future years. For example, for the plants predicted to be in the market in 1986 we generate draws of TFPQ, demand shocks and input costs using the AR(1) processes we have estimated (including a random shock with mean zero and standard deviation equal to that of the residuals of the AR(1) estimation). We in turn use the model to predict exit probabilities for each of these simulated 1986 plants. We repeat this process for each year until 1998. With the simulated distribution of plants in all years, we calculate average TFPQ (and other moments of the TFPQ distribution) for each year, considering only the set of plants predicted by the simulation to be present in the respective year. We do this for both simulation scenarios, and then calculate the average productivity gap between the two scenarios. This gap is our measure of the gain in average TFPQ attributable to better market selection related to tariff reductions over the period. We also calculate the $t$-statistic associated with this difference in means. We repeat this process 1000 times, given the potential sensitivity of the results in a single simulation to the random draws used at different steps of the process. The results we report correspond to averages over these 1000 simulations.

Notice that, since the shock processes for fundamentals are being held constant in these dynamic simulations, any difference in average TFPQ between the two scenarios responds to differences in the exit process associated with the alternative trade policies.[36] Notice also that the process just described abstracts from entry, in that the entire simulation is carried using only plants present in 1985. We also consider a version of the simulation where entrants are added to the sample. In this version, actual entrants are added to the simulated sample in each of the respective years and then these plants are treated the same as other incumbents in subsequent years.

Results for this dynamic simulation are reported in Table 6. Columns (1) to (3) report results for the version of the simulation where actual entrants are being added in each year, while columns (4) to (6) report results of the version that abstracts from entry. We begin by discussing the results that include entry. Column (1) reports the means and standard deviations of the log of TFPQ in the actual tariffs scenario, column (2) reports these statistics for the 1984 tariffs scenario, and column (3) reports the difference between columns (1) and (2), and $t$-statistics for these mean differences (in square brackets). In reporting the results, we find it instructive to show results for pooled years so that we compare and contrast the period when tariffs remained relatively high, 1986–1991, to the period during which tariffs were substantially reduced, 1992–1998. Our results indicate that the change in tariffs from the initial 1984 level generates insignificant gains in average TFPQ between 1986 and 1991. By contrast, the results show a large gain in average TFPQ between 1992 and 1998 of 2.1 log points which is significant at the 5% level for the entire sample of plants.[37]

Results excluding entry (columns (4)–(6)) allow us to explore both the extent of entry selectivity, and whether productivity gains are larger for the set of plants that faced the initial set of distortions for a longer time. The results in columns (4)–(6) of Table 6 show larger gains in TFPQ from the reduction in tariffs relative to the 1984 level when the simulation is carried out for the 1985 incumbents alone[38].

[36] Different random draws are an additional source of difference in average TFPQ between the two scenarios. But, these differences should be very close to 0 on average, given the large number of plants and our 1000 simulation rounds.

[37] For an idea of how closely our simulation using actual tariffs tracks actual average TFPQ, consider splitting the overall average TFPQ value reported column (1) of Table 4 into a pre-1992 value and a 1992–1998 value. This yields an increase of 1.8 log points between the two subperiods to be compared with the simulated 1.3 points increase reported in column (1) of Table 6. Keep in mind, however, that the counterfactual simulation is not really designed to replicate the actual evolution of average TFPQ, since we keep everything but tariff-related exits constant. Many other forces surely affect the actual evolution of the TFP distribution in different directions.

[38] To address concerns that entry responds endogenously to the increased exit, potentially eroding the gains from improved selection in the long run (Fattal, 2011), we conducted an extended version of the simulation. In this version, we impose entry of the same magnitude as exit and run the simulation for 50 periods. Estimated average productivity gains are even larger than in our baseline simulation (see Web Appendix, Table WA8).

**Table 6**
Average TFPQ using exit between $t-1$ and $t$ as projected by exit model.

| Average TFPQ (using projected $TFPQ_{it}$ for simulated continuers and actual $TFPQ_{it}$ for actual entrants) | | | | | | |
|---|---|---|---|---|---|---|
| Sample | All plants | | | 1985 incumbents | | |
| | Actual tariffs (1) | 1984 tariffs (2) | Difference (3) | Actual tariffs (4) | 1984 tariffs (5) | Difference (6) |
| 1986–1991 | 1.127 | 1.1247 | 0.0022 | 1.0894 | 1.0869 | 0.0025 |
| | (0.8021) | (0.8023) | [0.30] | (0.7907) | (0.7908) | [0.30] |
| 1992–1998 | 1.1403 | 1.1195 | 0.0207** | 1.1097 | 1.0842 | 0.0256** |
| | (0.9507) | (0.9518) | [2.15] | (0.9418) | (0.9452) | [2.05] |
| 1986–1998 | 1.133 | 1.1223 | 0.0106* | 1.0971 | 1.0858 | 0.0113 |
| | (0.8722) | (0.8743) | [1.78] | (0.8512) | (0.8552) | [1.60] |

*Note*: This table reports the simple mean of TFPQ for groups of plants simulated to participate in the market using the estimated probit model reported in columns (1) and (2) of Table 6. Figures reported are averages over 1000 simulations. Standard deviations in parentheses in columns (1), (2), (4) and (5); $t$-statistics for mean differences in square brackets in columns (3) and (6). The probability that a plant exits is estimated using actual values of tariffs in the results reported in columns (1) and (4), while tariffs are set at their 1984 value in the results reported in columns (2) and (5). Figures in columns (1)–(3) include plants that entered after 1985, while columns (4)–(6) only include plants present in 1985.

**Table 7**
Descriptive statistics of simulated TFPQ in 1998.

| | Actual tariffs (1) | 1984 tariffs (2) |
|---|---|---|
| Mean | 1.1352 | 1.1048 |
| Standard deviation | 0.9811 | 0.9818 |
| 1st percentile | −1.1335 | −1.1812 |
| 10th percentile | −0.0932 | −0.1212 |
| 50th percentile | 1.1245 | 1.0947 |

*Note*: This table reports descriptive statistics for the simulated distribution of TFPQ for 1998. The simulation uses actual tariffs in column (1) and 1984 tariffs in column (2). Reported figures are averages over 1000 simulations.

Table 7 helps illustrate how the implied change in average TFPQ is accounted for by the increased exit of less efficient plants. Columns (1) and (2) in Table 7 report the mean, standard deviation, and the 1st and 50th percentiles of the simulated TFPQ in 1998 for the sample of plants predicted to survive up to that year given the actual and 1984 tariffs, respectively. The simulated TFPQ for plants in the lowest percentile of simulated TFPQ is 5 log points higher when choosing the plants predicted to survive with actual tariffs compared to when the 1984 tariffs are used. While we also observe higher productivity at the median when choosing the plants predicted to survive with actual instead of the 1984 tariff levels, the difference is smaller than for the first percentile. These results suggest that the lower tail of the productivity distribution is being trimmed with the lower tariff.

To put the results in Tables 7 and 8 in context, we note that within sector aggregate productivity in our sample increased 14 log points in 1992–1998 (Fig. 2). From that perspective, increases in average productivity of 2 points from a change solely in the market selection process driven by trade reform alone are substantial.

### *5.2. Effects of trade on reallocation and productivity growth of incumbents*

While the focus in our paper has been on the impact of trade on plant exits and, in turn, on productivity, we are also interested in examining the impact of reduced tariffs on the productivity of continuing establishments. Continuing plants may be induced to become more productive through increased technology adoption and greater exposure to best practices world-wide. It may also be the case that, by cutting rents from market power, increased competition from trade may reduce the incentives to innovate.

To examine these hypotheses, we estimate a simple differences-in-differences specification regressing the log first difference of TFPQ for continuing plants on year effects, detailed industry effects and the change in tariffs (at the 4-digit level). This specification is similar to the analysis in Pavcnik (2002) for the case of Chile, but we take advantage of the Colombian data to improve on two dimensions. First, we have a better measure of productivity (TFPQ instead of TFPR). Second, cross-sectional variability in trade liberalization allows us to disentangle the effects of tariff reductions from general time effects.[39] Results are presented in Panel 1 of Table 8. We find evidence that continuing plants in industries with larger tariff reductions have greater within plant growth rates in productivity. The point estimate suggests that reducing tariffs from 60 to 20 percent (approximately the average size of the tariff reduction) would yield a within plant increase in productivity

[39] Cross-sectional variation in tariffs is also used in a related exercise by Lileeva and Trefler (2010). Their focus is on the debate about whether rising productivity is ever a consequence rather than a cause of exporting. They assess to what extent Canadian firms experienced a rise in productivity due to improved access to U.S. markets.

**Table 8**
Alternative effects of trade reform on aggregate and plant-level productivity.

Panel 1: Plant-level growth of TFP against the change in tariffs for the plant's sector

| | TFPQ | TFPR |
|---|---|---|
| Change in tariffs | −0.0747*** | −0.0525*** |
| | (0.0197) | (0.0182) |
| Sector effects | 4-digits | 4-digits |
| Year effects | Yes | Yes |
| $R^2$ | 0.0129 | 0.0247 |
| $N$ | 56,113 | 56,113 |

Panel 2: Plant-level output share in its 3-digit sector against TFP and tariffs for the sector

| | TFPQ | TFPR |
|---|---|---|
| TFP | 0.4380*** | 0.3983*** |
| | (0.0193) | (0.0248) |
| Tariffs*TFP | −0.2112*** | −0.0615** |
| | (0.0240) | (0.0309) |
| Tariffs | 0.0379 | −0.0885* |
| | (0.0381) | (0.0474) |
| Sector effects | 3-digits | 3-digits |
| Year effects | Yes | Yes |
| $R^2$ | 0.0780 | 0.0712 |
| $N$ | 66,875 | 66,875 |

Panel 3: 3-digit sector productivity against tariffs for the sector

| | TFPQ | | TFPR | |
|---|---|---|---|---|
| | Overall sector productivity | OP cross-term | Overall sector productivity | OP cross-term |
| | (1) | (2) | (3) | (4) |
| Tariffs | −0.2052** | −0.1940** | −0.1324* | -0.0545 |
| | (0.0825) | (0.0790) | (0.0728) | (0.0355) |
| Sector effects | 3-digits | 3-digits | 3-digits | 3-digits |
| Year effects | Yes | Yes | Yes | Yes |
| $R^2$ | 0.8268 | 0.7779 | 0.8540 | 0.8600 |
| $N$ | 336 | 336 | 336 | 336 |

Robust standard errors in parentheses. Panels 1 and 2 present regressions at the plant level, while Panel 3 presents a regression at the level of 3-digit sectors. Sector effects are included at the most disaggregate level that is both possible and consistent with the regression. In Panel 2 sector effects are included at a level of disaggregation consistent with the calculation of output shares included in the regression. Our industry productivity measure in columns (1) and (3) of Panel 3 is the output-weighted plant-level TFP. Columns (2) and (4) of that panel present the cross term of the Olley–Pakes decomposition of sector productivity. Tariffs at 3-digit level are weighted averages of tariffs at 4-digit level, where output shares are used as weights. In columns (3) and (4) output to construct weights is deflated with sector-level prices.

* Significant at 10%; ** Significant at 5%; *** Significant at 1%.

of about 3 log points. Put together with the results in the prior subsection, the trade reforms appear to increase average plant-level productivity both by cutting off the lower tail of the productivity distribution and by increasing productivity among continuing plants.

In the top panel of Table 8, we also show the estimated within plant change in productivity if we use the TFPR measure rather than TFPQ, as Pavcnik and others have in the past. We find that the impact of the change in tariffs is somewhat mitigated—with the estimated coefficient implying that reducing tariffs from 60 to 20 percent would yield an increase in TFPR of about 2 log points. Thus, the effect is one third lower compared to the effect when the physical productivity measure is used. This reduction in the magnitude of the effect reflects the composite nature of the TFPR measure—recall, for example, that TFPQ and prices are inversely correlated, implying a mitigated impact when using TFPR to measure productivity.

Second, trade reform may have affected the overall allocation of activity. The increased probability of the exit of low productivity plants may be one reason for an improvement of the allocation of activity, but more dynamic adjustments of incumbent plants and entry of establishments that are more productive may also work in the same direction. We examine the impact of trade opening on the reallocation of activity by conducting both plant-level and sector-level analyses. Both of these analyses should be interpreted as providing insights into how the level of tariffs impacts the covariance between market share of output and productivity. At the plant level, we regress the share of the plant's output in its 3-digit sector on productivity, tariffs and the interaction of tariffs and productivity while also controlling for sector and year effects. The results reported in Panel 2 of Table 8 show that lower tariffs increase the covariance between plant-level TFPQ and market share, i.e., the coefficient on the interaction term of tariffs and productivity is negative. The point estimates imply that reducing tariffs from 60 to 20 percent increases the covariance by 0.084. If we use TFPR instead of TFPQ, we find that reducing tariffs in the same manner increases the covariance by 0.025. Again, this mitigated effect likely reflects the composite nature of TFPR relative to TFPQ.

Similarly, we can use the Olley and Pakes (1996) (OP) sector-level decomposition methodology to compute the covariance between market share and plant-level productivity for every 3-digit sector in each year. We then estimate a simple differences-in-differences specification with the dependent variable being the 3-digit yearly OP cross-term and the explanatory variables including industry effects, year effects and 3-digit tariffs.[40] Tariffs at the 3-digit level are constructed as weighted averages of 4-digit level tariffs, where the weights are output shares.[41] Column (2) of Panel 3 of Table 8 shows that sectors with greater tariff cuts experience a larger increase in the OP cross-term. The point estimate suggests that reducing tariffs from 60 to 20 percent increases the OP cross-term by 7.8 log points. This improved allocation is a large effect relative to either the within plant increases for continuing plants and the market selection effects discussed above. Note however that this reallocation effect is partly driven precisely by these market selection effects. That is, more productive plants may increase their market share not only at the expense of less productive continuing plants but also at the expense of less productive plants which exited the market. When we use TFPR instead of TFPQ to look at the reallocation effect of tariffs, the point estimate suggests that reducing tariffs from 60 to 20 percent increases the cross term by only 2 log points. Again, a substantially mitigated effect, almost 75% lower than the effect we find with our improved measure of physical productivity.

Finally, we note that this simple difference-in-difference methodology can be used to quantify the overall effect of trade reforms on industry productivity.[42] The first column in Panel 3 of Table 8 shows the results for this specification. This exercise indicates that a reduction in tariffs from 60 percent to 20 percent increases average industry productivity by 8.2 log points. The latter effect is the combined effect of improved average plant-level productivity and improved allocation, where as discussed improved allocation accounts for 7.8 of the total 8.2 improvement. As indicated, there is no exact decomposition of the role of market selection in this context since it contributes to both increases in average plant-level productivity (the results in the prior section) and improvements in allocation. Finding the overall contribution of market selection would require more structure in modeling both the changes of productivity and market shares of incumbents and the contribution of entering and exiting plants. However, combining the 2.1 log point effect of market selection on the unweighted average productivity from the prior section with the 7.8 log point effect of improved allocative efficiency yields an implied 9.9 log point combined effect of selection and improved allocative efficiency. Appropriate caution needs to be used for this simple calculation since this combines results from very different methodologies but this 9.9 log point combined effect is quite large relative to the overall 14 log point effect observed in Fig. 2.

If we use TFPR rather than TFPQ for this industry-level exercise, the reduction in tariffs from 60 to 20 percent increases average industry productivity by 5.3 log points. In interpreting this result, we note that we have found mitigated effects of trade reform on productivity on all channels when using TFPR—a reduced impact on selection, a reduced impact on within plant productivity, and a reduced impact on the covariance between size and productivity. We note that the magnitude of the reduced impact is especially pronounced on the selection channel and the size/productivity covariance.

Before moving to the following section, it is worth pointing that there are dimensions in which trade reform can be damaging to aggregate productivity, in ways that our analysis cannot take into account. An important one is that, given adjustment costs, resources freed by exiting and shrinking establishments may in fact not be allocated to better uses but left idle.

## 6. Robustness analysis

We have conducted a number of robustness checks of the main result in Table 5. We discuss those additional exercises in this section, and present some of their results in Tables 9 to 11.

We begin by testing the robustness of our results to using factor elasticities proxied by cost shares when estimating TFPQ (Table 9) instead of using an IV approach. This change affects both the TFPQ measure and the demand shock and demand elasticity measures, given that TFP is used as an instrument in estimating demand elasticities. Our main results are robust to this change. TFP, the demand shock, and materials prices, all continue to be important determinants of the probability of exit, with expected signs. More importantly, there is a significant increase in the marginal effect of productivity induced by the reduction in tariffs. This effect is only present if physical productivity, rather than revenue productivity, is used to

[40] Other studies look at reallocation by examining the relative employment growth of more technologically advanced firms in sectors exposed to trade (e.g., Bloom et al., 2011). However, the theoretical predictions regarding improvement in allocative efficiency apply directly to the allocation of output across producers so we focus on market share measured by output share within a sector. In addition, the implications for factor reallocation are more complex given the presence of adjustment costs. In related work in Eslava et al. (2010a) we have found evidence of sluggish factor adjustment in Colombia that was impacted by the market reforms. For example, we found that plants became more likely to downsize in response to adverse shocks following reforms. As such, the appropriate approach to studying the impact of trade liberalization on factor reallocation would be to explore the impact of tariff changes within the context of the factor adjustment model we considered in this earlier work.

[41] When using TFPR the output shares are constructed from output deflated with sector-level prices. Panel 3 results, however, are virtually identical if plant-level prices are used in the construction of these shares.

[42] The index of industry-level productivity we use here is a geometric mean of plant-level productivity. Specifically, for TFPQ we construct the output-weighted average of TFPQ (where the latter is log based). For TFPR, we construct the revenue-weighted average of TFPR (also log based).

**Table 9**
Determinants of exit probability using TFP estimated with factor elasticities equal to cost shares.

| Regressor | Ef. tariffs at 60% (1) | Ef. tariffs at 20% (2) | Difference (3) | Ef. tariffs at 60% (4) | Ef. tariffs at 20% (5) | Difference (6) |
|---|---|---|---|---|---|---|
| Lagged TFP | −0.0085*** | −0.0127*** | 0.0042* | | | |
| | (0.0015) | (0.0026) | (0.0023) | | | |
| Lagged energy prices | −0.0005 | 0.0022 | −0.0026 | | | |
| | (0.0021) | (0.0033) | (0.0026) | | | |
| Lagged materials prices | 0.0177*** | 0.0313*** | −0.0136*** | | | |
| | (0.0025) | (0.0044) | (0.0038) | | | |
| Lagged demand shock | −0.0269*** | −0.0319*** | 0.0049*** | | | |
| | (0.0007) | (0.0014) | (0.0012) | | | |
| Lagged demand elasticity | 0.0405 | 0.0904 | −0.0499 | | | |
| | (0.1833) | (0.1560) | (0.0356) | | | |
| Lagged TFPRC | | | | −0.0074*** | −0.0096** | 0.0023 |
| | | | | (0.0023) | (0.0039) | (0.0033) |
| Lagged sector energy prices | | | | 0.0101 | 0.0039 | 0.0063 |
| | | | | (0.0067) | (0.0108) | (0.0085) |
| Lagged sector material prices | | | | 0.0362*** | 0.0517*** | −0.0155 |
| | | | | (0.0122) | (0.0120) | (0.0117) |
| Effective tariffs | −0.0189*** | −0.0210*** | 0.0022 | −0.0136** | −0.0145* | 0.0009 |
| | (0.0056) | (0.0069) | (0.0013) | (0.0067) | (0.0076) | (0.0009) |
| Other reforms index (level and interactions) | Yes | | | Yes | | |
| Sector effects | 4-digit | | | 4-digit | | |
| GDP growth | Yes | | | Yes | | |
| Goodness of fit | Pseudo-R2 = 0.081, Wald chi2 = 1617.28 | | | Pseudo-R2 = 0.029, Wald chi2 = 806.6 | | |
| *N* | 58,290 | | | 58,290 | | |

This table reports marginal effects from a probit estimation of the probability of exit, equivalent to the estimation in Table 5. The TFP measure used in this estimation is calculated using cost shares as factor elasticities, whereas the factor elasticities used to calculate the TFP included in Table 5 come from an IV estimation of the production function. Pseudo-R2 is the McFadden Pseudo R2.

* Significant at 10%; ** Significant at 5%; *** Significant at 1%.

**Table 10**
Determinants of exit probability: controlling for the capital stock and its interaction with tariffs and other reforms, and replacing GDP growth with time effects.

| | Ef. tariffs at 60% (1) | Ef. tariffs at 20% (2) | Difference (3) | Ef. tariffs at 60% (4) | Ef. tariffs at 20% (5) | Difference (6) |
|---|---|---|---|---|---|---|
| Lagged TFPQ | −0.0191*** | −0.0254*** | 0.0063* | −0.0164*** | −0.0207*** | 0.0043* |
| | (0.0053) | (0.0048) | (0.0034) | (0.0015) | (0.0024) | (0.0022) |
| Lagged energy prices | 0.0007 | 0.0040 | −0.0033 | 0.0008 | 0.0035 | −0.0027 |
| | (0.0022) | (0.0036) | (0.0028) | (0.0021) | (0.0030) | (0.0025) |
| Lagged materials prices | 0.0184*** | 0.0327*** | −0.0143** | 0.0188*** | 0.0273*** | −0.0085** |
| | (0.0055) | (0.0074) | (0.0044) | (0.0025) | (0.0040) | (0.0035) |
| Lagged demand shock | −0.0195*** | −0.0239*** | 0.0044*** | −0.0224*** | −0.0242*** | 0.0018* |
| | (0.0052) | (0.0048) | (0.0017) | (0.0007) | (0.0012) | (0.0011) |
| Lagged demand elasticity | 0.0169 | 0.0320 | −0.0151 | 0.0043 | 0.0162 | −0.0119 |
| | (0.0528) | (0.0468) | (0.0095) | (0.0495) | (0.0384) | (0.0126) |
| Effective tariffs | −0.0252 | −0.0290 | 0.0038 | −0.0026 | −0.0027 | 0.0000 |
| | (0.0163) | (0.0222) | (0.0060) | (0.0067) | (0.0069) | (0.0002) |
| Lagged log capital | −0.0051*** | −0.0062*** | 0.0011 | | | |
| | (0.0016) | (0.0012) | (0.0016) | | | |
| Other reforms index (level and interactions) | Yes | | | Yes | | |
| Sector effects | 4-digit | | | 4-digit | | |
| GDP growth | Yes | | | No | | |
| Time effects | No | | | Yes | | |
| Goodness of fit | Pseudo-R2 = 0.08, Wald chi2 = 1601.5 | | | Pseudo-R2 = 0.087, Wald chi2 = 1797.6 | | |
| *N* | 58,290 | | | 58,290 | | |

*Notes*: This table reports marginal effects from a probit estimation of the probability of exit, equivalent to the estimation in Table 5. In contrast to that estimation, columns (1)–(3) include as additional regressors the lagged log of the stock of capital, and interactions of this variable with tariffs and with the index of other reforms, while columns (1)–(3) control for aggregate effects using time effects rather than GDP growth. Robust standard errors in parentheses. Pseudo-R2 is the McFadden Pseudo R2.

* Significant at 10%; ** Significant at 5%; *** Significant at 1%.

measure TFP. As before, the increase in the marginal effect of productivity induced by the fall in tariffs is cut by half and becomes statistically insignificant when revenue productivity is used.

A number of empirical papers on market selection include controls for plant size and age and find that younger and smaller plants are more likely to exit. In our view, these variables are typically included to proxy for unobserved market

**Table 11**
Determinants of exit probability: Excluding plants in the 20% most concentrated 4-digits sectors, and introducing changes in tariffs.

| | Ef. tariffs at 60% (1) | Ef. tariffs at 20% (2) | Difference (3) | Ef. tariffs at 60% (4) | Ef. tariffs at 20% (5) | Difference (6) |
|---|---|---|---|---|---|---|
| Lagged TFPQ | −0.0160*** | −0.0227*** | 0.0066*** | −0.0158*** | −0.0215*** | 0.0057** |
| | (0.0015) | (0.0027) | (0.0024) | (0.0015) | (0.0026) | (0.0024) |
| Lagged energy prices | 0.0007 | 0.0042 | −0.0035 | 0.0008 | 0.0038 | −0.0030 |
| | (0.0022) | (0.0035) | (0.0027) | (0.0021) | (0.0033) | (0.0027) |
| Lagged materials prices | 0.0195*** | 0.0330*** | −0.0136*** | 0.0178*** | 0.0297*** | −0.0119*** |
| | (0.0026) | (0.0045) | (0.0039) | (0.0026) | (0.0044) | (0.0039) |
| Lagged demand shock | −0.0228*** | −0.0271*** | 0.0043*** | −0.0225*** | −0.0263*** | 0.0038*** |
| | (0.0007) | (0.0013) | (0.0011) | (0.0007) | (0.0013) | (0.0011) |
| Lagged demand elasticity | −0.0144 | −0.0007 | −0.0137 | 0.0104 | 0.0244 | −0.0140 |
| | (0.0687) | (0.0589) | (0.0125) | (0.0529) | (0.0450) | (0.0105) |
| Effective tariffs | −0.0193*** | −0.0216*** | 0.0022* | −0.0173*** | −0.0191*** | 0.0018 |
| | (0.0057) | (0.0070) | (0.0013) | (0.0057) | (0.0069) | (0.0012) |
| Change in effective tariffs | | | | −0.0031 | −0.0034 | 0.0003 |
| | | | | (0.0069) | (0.0076) | (0.0007) |
| Other reforms index (level and interactions) | Yes | | | Yes | | |
| Excluding most concentrated sectors | Yes | | | No | | |
| Sector effects | 4-digit | | | 4-digit | | |
| GDP growth | Yes | | | Yes | | |
| Goodness of fit | Pseudo-R2 = 0.077, Wald chi2 = 1552.4 | | | Pseudo-R2 = 0.079, Wald chi2 = 1636.3 | | |
| *N* | 57,213 | | | 57,816 | | |

*Notes*: This table reports marginal effects from a probit estimation of the probability of exit, equivalent to the estimation in Table 5. In contrast to that estimation, in this table we exclude plants belonging to the 20% most concentrated sectors at the 4-digit level (columns (1)–(3)), or introduce as additional regressors the change in effective tariffs and its interactions with all fundamentals (columns (4) to (6)). Pseudo-R2 is the McFadden Pseudo R2.

* Significant at 10%; ** Significant at 5%; *** Significant at 1%.

fundamentals. By contrast, we have a very rich set of fundamentals that are motivated by the theory. For example, our demand shock measure captures variation in scale not driven by variation in productivity, and as such is a measure of size consistent with theory. A case could be made for the inclusion of additional variable related to size—namely the capital stock. As a robustness check, we estimated similar specifications to that reported in Table 9, but also including the lagged capital stock, and its interactions with tariffs and the index of other reforms (Table 10, columns (1)–(3)). Our results are remarkably robust to the inclusion of this variable. Moreover, we find that plants with a bigger capital stock are associated with a lower probability of exit. We do not include capital in the baseline specification both to keep the focus on market fundamentals, and because extending the dynamic simulation of Tables 6 and 7 to keep track of the (endogenous) capital stock requires making ad-hoc assumptions.

Table 10 also presents results of re-estimating the specification in Table 5 using year effects to replace GDP growth and the index of other reforms (but not its interactions with market fundamentals) as our control for aggregate shocks. These results are reported in columns (4)–(6). Despite the fact that this approach soaks up much of the variability in policy, our result that trade reform enhances the market selection mechanisms is still picked up by this estimation, though the difference in the marginal effect of TFPQ reported in column (6) of Table 10 is smaller than that in Table 5. The fact that the market selection effect appears even in this specification highlights the importance of the reduction in the dispersion of tariffs as a driving force behind enhanced market selection.

Another possible concern is that the variation in tariff reductions across sectors is endogenous. To address this possibility, we re-estimate Table 5 after dropping the 20% most concentrated 4-digit sectors in our sample, according to the Herfindahl index used in Table 3. We do this to dispel concerns that in very concentrated sectors individual establishments could have influenced the tariff rate in the sector. The results, presented in Table 11 (columns (1)–(3)) are very similar to those that include all sectors in the sample. In addition, if the story of lobbying by individual establishments was behind the higher tariffs in a sector, we would expect the correlation between the Herfindahl index and tariffs to be positive. Instead, we find that this correlation is −0.05 and insignificant. The robustness of our results to addressing a potential endogeneity in tariffs is perhaps not surprising, not because producers did not lobby for tariffs, or because their lobby was unsuccessful, but rather because lobby likely occurs at the sector rather than the establishment level.

We also explored whether the impact of trade reforms takes time by including the change in tariffs (in addition to the tariff level) in the specification. We found that the results reported in Table 5 are robust to inclusion of the change of tariffs as an additional explanatory variable and the latter was by itself not significant. This is shown in Table 11, columns (4)–(6).

In addition, we explored concerns about biases in the estimation of shocks and demand elasticities due to the possibility that product quality and TFPQ move together. First, we estimated the sector-level correlation between TFPQ and relative prices and dropped the 4-digit sectors with the top 20% correlations (i.e., those exhibiting *less negative* correlations) which may be presumably the sectors where TFPQ and product quality move most closely together. The effects of all fundamentals on exit remain similar in size and significance in this version of the estimation; some of the changes in those effects induced by trade liberalization are estimated less precisely, probably due to the smaller sample—close to 1/4 of our observations are lost in this robustness check. Second, to address the potential biases in the estimation of demand shocks and elasticities, we estimate the interacted model (5), but leaving out the level and interaction effects of the demand shocks and elasticities and including instead level and interaction effects of the output price. The results are again similar though, not surprisingly, less precise since, as noted in Table 2, TFPQ and output prices are strongly negatively correlated.[43]

## 7. Conclusion

There is a lively ongoing debate about the economic impact of trade opening. Detractors of globalization claim that intensified international competition can have devastating effects by shutting down domestic industries and destroying jobs. In the other camp, there are those that believe that foreign competition is healthy as it induces reallocation of resources to their most efficient use. In the current paper, we assess whether allocative efficiency and productivity growth are enhanced by lower tariffs. In complementary research, we are exploring the impact of trade liberalization on the earnings of workers through displacement (Eslava et al., 2010b).

We find that trade reforms impact productivity through many channels. Trade reforms increase productivity by making it more likely that low productivity plants exit, through increases in within plant productivity and through an increased covariance between plant-level productivity and market share. The quantitative impact of trade reform on these alternative channels is substantial. We find, for example, that the improved market selection channel yields an increase in average plant-level productivity of 2.1 log points in the five years that followed the trade reform in Colombia. We find that the within plant increase in productivity is about 3 log points. We find that the increase in the covariance between productivity and size contributes to an increase in the Olley–Pakes cross-term in an industry-level productivity decomposition of about 7.8 log points.

In identifying these effects, we have taken advantage of very rich data for Colombia that permits disentangling measures of revenue productivity into price and technical efficiency components. The underlying models of firm dynamics and the impact of trade reforms on these firm dynamics focus on the impact on technical efficiency but almost all of the related empirical literature studies the impact on measures of revenue productivity. We find that when we use the common revenue productivity approach to measuring plant-level productivity the estimated impact on all of the above channels is mitigated substantially. We find that it is especially the channels involving allocation effects—the market selection and the covariance between size and productivity—that are impacted. Indeed, if we use the commonly used measure of revenue productivity we do not find that trade reform impacts the marginal effect of productivity on exit. We do find an impact of trade reform on the covariance between size and productivity, but this effect is substantially reduced with respect to the one we estimate using physical productivity. For example, the impact on the Olley–Pakes cross-term drops to about 2 log points as opposed to the 7.8 log point effect we find when using measures of technical efficiency.

The difficulty with using revenue productivity is that it is a composite measure reflecting both plant-level price and technical efficiency effects. Since plant-level prices are endogenous and potentially reflect effects that work in different directions, revenue productivity measures can be difficult to interpret. On the one hand, theory predicts (and we find empirical evidence in support of this prediction) that more technically efficient plants will have lower marginal costs and charge lower prices. This inverse correlation between technical efficiency and prices will tend to dampen the variation in revenue productivity relative to measures of technical efficiency. Alternatively, the positive correlation between prices and demand effects (demand shocks and elasticities) works in the opposite direction—i.e., high prices may also reflect favorable demand conditions for the plant. In an environment of trade reform, these issues are further complicated since trade reform may impact market structure and demand conditions differently than the relationship between plant survival and technical efficiency.

We think that our results highlight the importance of distinguishing between measures of revenue productivity and technical efficiency in studying firm dynamics in general, and particularly in an environment of market reform. Given that the results are sensitive to this distinction, we also think our results suggest that future work should seek both to understand the underlying demand side of firm- and plant-level heterogeneity and to understand the impact of market reforms (such as trade reforms) on the demand side.

The evidence presented in this paper contributes to our understanding of the channels through which trade opening impacts productivity. Indeed, we document that it is mainly through reallocation that lower tariffs impact aggregate productivity. In particular, we find that the exit of low productivity plants is intensified by international competition as market selection becomes less dependent on barriers to entry. At the same time, the output share of relatively productive plants tended to expand after trade liberalization at the expense of less productive plants. These results imply that international competition induces productivity enhancing reallocation. While this reallocation leads to a productivity boost, it also yields substantial churning in input markets. Among other things this yields worker displacement, which in labor markets with frictions can cause earning losses. This is an important dimension of trade liberalization which, as noted, we are exploring in Eslava et al. (2010b).

[43] Results of these last two exercises are reported in the Web Appendix, Tables WA9 and WA10.

## Supplementary material

The online version of this article contains additional supplementary material.
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