

Trade, Technology, and Productivity: A Study of Brazilian Manufacturers, 1986-1998*

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Abstract

Brazil's trade liberalization between 1990 and 1993, and its partial reversal in 1995, are used to study how reduced inward trade barriers affect productivity. The production function of Brazilian manufacturers is estimated at the *ISIC3* two-digit level under various alternatives, including an extension of Olley and Pakes' (1996) procedure. Firm-level productivity is inferred and then related to trade. Findings suggest that (1) foreign competition pressures firms to raise productivity markedly, whereas (2) the use of foreign inputs plays a minor role for productivity change. (3) The shutdown probability of inefficient firms rises with competition from abroad, thus contributing positively to aggregate productivity. Counterfactual simulations indicate that the competitive push (1) is an important source of immediate productivity change, while the elimination of inefficient firms (3) unfolds its impact slowly.

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The repeal of trade barriers might exert a positive impact on productivity change and country-wide growth. A body of empirical evidence at the macroeconomic level across countries (Ben-David 1993, Sachs and Warner 1995), at the level of sectors (Keller 2000, Kim 2000), and at the level of firms or plants points towards a positive effect of trade on productivity change (Tybout, Melo and Corbo 1991, Levinsohn 1993, Roberts and Tybout, eds 1996, Pavcnik 2002). However, (Rodríguez and Rodrik 2000) and others contest the cross-country evidence for measurement and unresolved endogeneity problems.

The micro-econometric evidence lacks an identification of the exact mechanisms by which trade may induce productivity change and provides little guidance to policy makers who contemplate trade reform. Endogenous trade policies potentially confound estimates. Moreover, several firm-level and aggregate processes may drive productivity change simultaneously. Tybout (2002) concludes in a recent literature review that “it is difficult to find studies that convincingly link these processes to the trade regime.”

Employing a newly constructed data set of Brazilian manufacturers for the years 1986-1998—a period of major changes to inward trade barriers in Brazil—the present paper separates and analyzes three distinct mechanisms (*channels*) behind trade-induced productivity change at the level of firms. These candidate *channels* are:

1. *Competitive Push*: The removal of inward trade barriers increases competition on the product market. This may induce firms to improve existing processes and owners to address agency problems.
2. *Foreign Input Push*: High-quality equipment and intermediate goods allow firms to adopt new production methods. This can raise efficiency.

These two effects tend to shift a *firm's* productivity. In addition, a separate group of trade effects on productivity can only be observed at the level of *sectors or industries*. The focus lies on

3. *Competitive Elimination*: Increased foreign competition makes the least efficient firms shutdown. Their exit raises average productivity.

For the first time, the present paper can assess the relative importance of these three channels *vis à vis* each other, and evaluates their overall importance for productivity change in Brazilian manufacturing during the years 1986-98. While trade-induced productivity changes at the firm level are present and significant even after controlling for possibly confounding effects and endogenous policies, the gains are moderate. After all, the largest gains from trade may indeed be those to consumers, as classic trade theory posits, and not so much those from productivity change.

Concretely, this paper asks: *How did Brazil's removal of inward trade barriers affect productivity among its medium-sized to large manufacturers?* Brazil's federal governments began to reform the tariff act in 1988. From 1990 to 1993, it slashed non-tariff barriers and tariffs to less than a quarter of their initial effective levels (Cavalcanti Ferreira and Rossi 2003).

Microeconomic studies on the *Competitive Push* (1) and *Competitive Elimination* (3) include Levinsohn (1993), Roberts and Tybout, eds (1996) and Pavcnik (2002). For Brazil, Cavalcanti Ferreira and Rossi (2003, sector data), Hay (2001, firm data), and Schor (2003, firm data) find a positive impact of trade reform on manufacturing productivity. Special variables in the present data set trace a firm's economic destiny—its exporting status, and its suspension or extinction. These groups of variables permit refinements in the estimation technique.

A unique feature of the present firm data is the information on foreign equipment acquisitions at the firm level. In addition, the use of foreign intermediate inputs is reported. So, the present data can identify the *Foreign Input Push* (2). To my knowledge, Feenstra, Markusen and Zeile (1992) and Fernandes (2003) are the only prior studies that can trace effects of intermediate inputs, though not of foreign equipment, on productivity at the micro-level (Korean business groups and Colombian manufacturers, respectively). Their studies suggest that productivity is positively related to the use of high-quality (foreign) intermediate goods.

The empirical strategy of the present study involves three stages. First, I obtain consistent firm-level productivity estimates for an unbalanced panel of 9,500 manufacturing firms and simultaneously control for all three channels of market-induced changes in a variant of the Olley and Pakes (1996) procedure. Second, I refine the estimation on a channel-by-channel basis and provide comparisons to two commonly used alternative productivity measures. Third, on the basis of those estimates, I simulate firm-level productivity change in the absence of single channels.

Evidence on the *Competitive Push* (1) suggests that firms raise their efficiency considerably in response to increased competitive pressure from abroad. To draw this conclusion, the analysis controls for the endogeneity of trade policy and the simultaneity of foreign market penetration, using the nominal exchange rate and sector-specific foreign producer prices as instrumental variables. Results for the *Foreign Input Push* (2) suggest that, in many sectors, the efficiency of foreign equipment and intermediate inputs is higher than the efficiency of domestic inputs. Foreign inputs enter the production functions explicitly. However, their overall efficiency contribution is minor. The adoption of new technologies can reduce productivity initially. Firms need

to put high-quality inputs to adequate use in order to achieve productivity gains. Possibly, Brazilian firms in several sectors do not succeed with necessary rearrangements in the short term. Third, firm turnover and the exit of the least productive firms contributes positively to productivity change in the aggregate. In an effort to evaluate this *Competitive Elimination* (3) directly, probabilities of Markov transitions between states of operation are estimated as functions of the trade regime. The exit probability increases strongly with foreign competition.

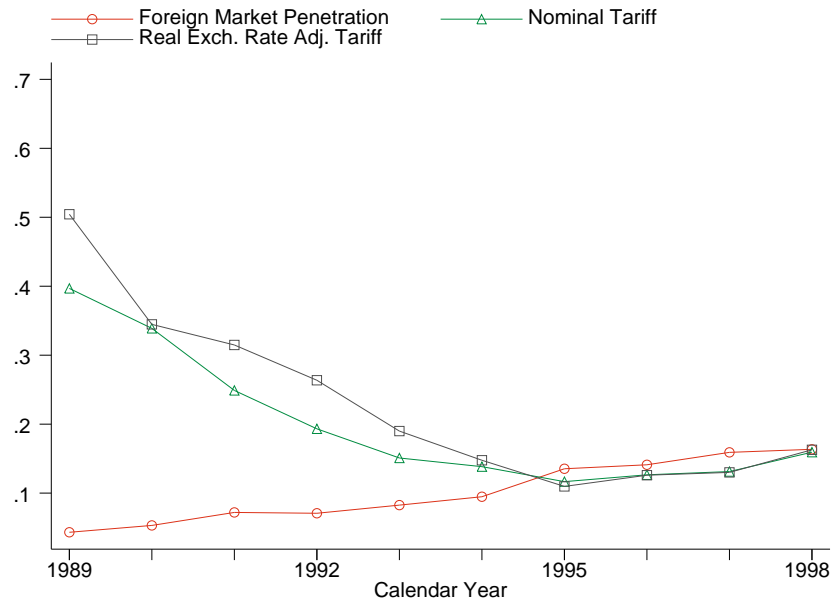
To understand the relative importance of the three channels, counterfactuals are evaluated in simulations. The counterfactuals ask how much less productivity change would have occurred through each channel had Brazil not reduced inward tariffs. These simulations show that the *Competitive Push* (1) is an important source of immediate productivity change, while the *Foreign Input Push* (2) is negligible and *Competitive Elimination* (3) exercises a detectable impact on productivity only gradually.

The remainder of the paper is organized as follows. Section 1 gives an overview of the Brazilian trade policy changes during the sample period. Section 2 describes the data. Section 3 obtains firm-specific productivity measures and provides immediate evidence on the three channels in a variant of the Olley and Pakes (1996) algorithm. Building on the resulting firm-level productivity estimates and two common alternatives, section 4 refines the estimation. Section 5 evaluates in counterfactual simulations how Brazil's trade policy affected productivity change through the three channels. Section 6 concludes.

1 Brazil's Trade Policy

For decades, policies of import substitution and industry protection were part of Brazil's broader development strategy. Until the early nineties, elevated tariffs, exchange rate controls and interventions, and especially prohibitive non-tariff barriers were intended to reduce competitive pressure from abroad. From the mid seventies until the late eighties, for instance, potential importers to Brazil underwent rigorous examinations whether their commodities were similar to domestic products. If so, their imports were banned. As a result, the Brazilian domestic market remained essentially closed for a broad range of foreign equipment, including computers.

In 1988, the federal government initiated a process of trade reforms that reduced both the level and the cross-industry dispersion of tariffs. However, the effect of these reforms was limited as non-tariff barriers remained unaltered and continued to be binding for many imports (Kume, Piani and Souza 2000). Only the Collor de Melo administration in 1990 was able to break with earlier



Source: Own calculations, tariffs weighted by imports (all manufacturing).

Figure 1: **Tariffs and foreign market penetration**

Brazilian policies. The government presented a detailed schedule for tariff reductions to be completed by 1994 and announced the elimination of non-tariff barriers. Tariffs on equipment not produced in Brazil, for instance, were immediately reduced to zero and non-tariff barriers were eliminated. Tariffs for information technology, however, remained at 40 percent in order to protect Brazil's fledgling computer industry. The government's main objectives for dismantling trade barriers were first to instill competition in inefficient sectors and second to discipline concentrated industries in their pricing power so that hyper-inflation could be fought more effectively. As a consequence, and contrary to common political-economy outcomes, mostly sectors with low efficiency performance were targeted with low tariffs. The liberalization programme was concluded in less than three years by July 1993. This speed and the far reaching removal of non-tariff barriers shocked the domestic manufacturing sector considerably. When president Cardoso took office in 1995, liberalization efforts were reversed in select sectors leading to renewed tariff dispersion.¹

¹Inflation was under control since August 1994, the Brazilian trade deficit had widened and new negotiations for the Southern Cone Customs Union MERCOSUR afforded an opportunity to partly reverse prior tariff reductions.

Figure 1 depicts tariff levels and market penetration for an import-weighted average of all manufacturing sectors. Brazil's elevated (depreciated) real exchange rate added to protection until 1994. To show this, a tariff series weighted by the real exchange rate is included alongside (the real exchange rate is set to unity in August 1994). Cavalcanti Ferreira and Rossi (2003) argue that, on average, the effective rate of protection was about 86 percent of the import price in 1987. According to their measure, effective protection fell to 18 percent by 1997. Brazil took hardly any steps to remove outward barriers to trade or to stimulate exports beyond existing policies (Veiga 1998). As a welcome consequence, the impact of trade reform on the import side can be largely isolated from other effects of trade. Foreign direct investment, a further key aspect of an economy's openness, rose strongly in Brazil over the same period and will be controlled for.

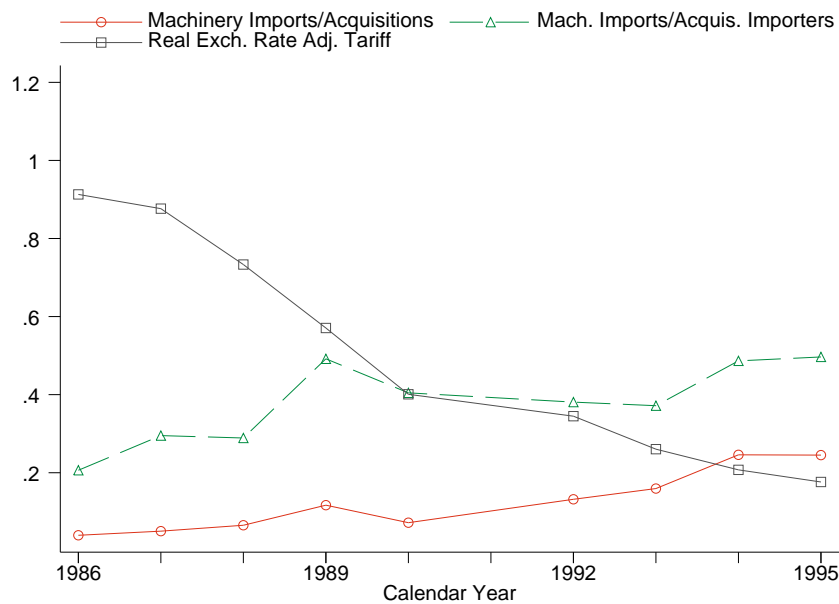
2 Data

An unbalanced panel of 9,500 medium-sized to large firms in Brazil's manufacturing sectors is constructed from the Brazilian statistical bureau's (*IBGE*) annual survey *Pesquisa Industrial Anual (PIA)*. The sample is not strictly representative for the manufacturing sector as a whole. Yet, to trace the effects of trade liberalization on productivity, only a random sample is needed that was selected independent of trade exposure. This is satisfied. The present section highlights the most important features of the data. A description of the sample and details on data construction are relegated to appendix A.²

Output and domestic inputs are deflated with sector-specific price indices (constructed on the basis of Brazilian wholesale price indices and input-output matrices). Capital stock figures and investments are deflated with economy-wide price indices (constructed on the basis of Brazilian wholesale price indices and economy-wide capital formation vectors). There is no producer price index for Brazil. The overall capital stock is inferred under a perpetual inventory method that controls for changes to accounting law in 1991. Foreign inputs are deflated with exchange-rate and tariff adjusted, sector-specific import-weighted foreign producer and wholesale price indices. This deflation procedure for foreign inputs ensures that production function coefficients on foreign inputs are not affected by any price-related correlation between them and firm-level productivity (which may depend on the exchange rate and tariffs).

Special state variables in *PIA* summarize a firm's state of operation and guarantee that observations with missing economic information are not con-

²Muendler (2003) presents an in-depth report on the *PIA* data base and the construction of firm-level panels for the period 1986 through 2001.



Source: Own calculations (all manufacturing).

Data: *Pesquisa Industrial Annual* for equipment acquisitions. Effective equipment tariffs from Kume et al. (2000) weighted by the national capital formation vector (*IBGE*).

Figure 2: Foreign equipment acquisitions

founded with a shutdown or temporary suspension of production. This is particularly important as it was common among Brazilian manufacturers between 1986 and 1998 to “mothball” for extended periods of time. Among the 9,500 firms, more than 1,100 state in at least one year that they suspended production.

Figure 2 plots the evolution of foreign equipment acquisitions between 1986 and 1995. Importers of foreign equipment before 1991 continue to invest in foreign equipment at roughly the same rate after 1991. However, the share of foreign equipment in total equipment acquisitions jumps up significantly. So, mostly firms that did not acquire foreign equipment before 1991 do so after trade liberalization.

3 Firm-level Productivity

Total factor productivity (*TFP*) measures the aspect of a firm’s production that physical factors such as capital, intermediate inputs, or labor of varying skills cannot explain. Apart from mere random shocks, managerial efforts, reorganizations, process innovations, and investments in the knowledge of the

work force affect *TFP*. These *TFP*-relevant efforts are unobservable here as in most data but they are alleged forces behind the three *channels* of trade-induced productivity change: the *Competitive Push*, the *Foreign Input Push*, and *Competitive Elimination*. Most importantly, it is a maintained hypothesis of the present and many earlier studies that the firms' competitive environment and trade barriers in particular influence *TFP*-relevant efforts (Nickell 1996, Djankov and Hoekman 2000, Pavcnik 2002).

For the first time, the present study assesses the three channels *vis à vis* each other. The present section discusses production function estimation and provides immediate evidence in a single framework. The following section 4 revisits and refines the estimation, and evaluates the overall importance of trade-induced changes for overall productivity in Brazilian manufacturing in simulations.

For purposes of the present analysis, I infer each firm's individual productivity through three alternative methods. All methods yield time-invariant sector-specific production coefficients, which serve as weights to remove the physical factor contributions from output and to arrive at *TFP*. While production function coefficients differ between these alternative methods, resulting productivity estimates exhibit largely the same covariation with other variables. The reason is that a firm's use of physical factors matters strongly for its *TFP* measure, whereas the level of the weights for those inputs matters less.

The first measure is Griliches and Mairesse's (1990) approximation to log *TFP*. The second productivity measure, log *TFP-OLS*, derives from plain OLS estimates of production functions on the unbalanced panel. The third measure, log *TFP-EOP*, results from an extended (efficiency-choice adjusted) Olley and Pakes estimation procedure. Both latter measures control for a potential efficiency difference between foreign and domestic inputs that would otherwise be attributed to overall *TFP*.

3.1 Production and foreign input efficiency

To measure the effect of foreign inputs on production directly, one can allow foreign inputs to carry a different efficiency parameter in Cobb-Douglas production. Suppose firm i produces with the same technology in every year t but with possibly different total factor productivity. Foreign equipment exceeds the efficiency of Brazilian equipment by a factor $(1 + \gamma_K)$, foreign intermediate goods surpass domestic intermediate goods' efficiency by a factor $(1 + \gamma_M)$.

The share of foreign equipment in total equipment is $\kappa_{i,t}^f \equiv K_{i,t}^{for} / (K_{i,t}^{dom} + K_{i,t}^{for})$. Similarly, $\mu_{i,t}^f \equiv M_{i,t}^{for} / (M_{i,t}^{dom} + M_{i,t}^{for})$. Since $\ln(1 + c) \approx c$ for any small

c , the contribution of capital to production is approximately $\beta_K \ln[K_{i,t}^{dom} + (1 + \gamma_K)K_{i,t}^{for}] \approx \beta_K \gamma_K \kappa_{i,t}^f + \beta_K k_{i,t}$, where $k_{i,t}$ is log total equipment. A similar approximation holds for $\mu_{i,t}^f$.³ So, production becomes

$$y_{i,t} \approx \beta_{bl} l_{i,t}^{bl} + \beta_{wh} l_{i,t}^{wh} + \beta_K \gamma_K \kappa_{i,t}^f + \beta_K k_{i,t} + \beta_S s_{i,t} + \beta_M \gamma_M \mu_{i,t}^f + \beta_M m_{i,t} + \omega_{i,t} + \epsilon_{i,t}. \quad (1)$$

Lower-case letters denote the log of variables. $Y_{i,t}$ is output. $L_{i,t}^{bl}$ and $L_{i,t}^{wh}$ denote the number of blue and white-collar workers on December 31. There are three parts of the capital stock: Domestic and foreign equipment, $K_{i,t}^{dom}$ and $K_{i,t}^{for}$, and structures $S_{i,t}$.⁴ $M_{i,t}^{dom}$ and $M_{i,t}^{for}$ are domestic and foreign intermediate inputs. The error term $\epsilon_{i,t}$ in (1) is a white noise shock to the production technology, its variance (but not its mean under EOP) is taken to be constant across firms in a sector, and its realization is unknown both to a firm and the researcher. $\omega_{i,t}$ is the management controlled part in a firm's log *TFP*, unobserved by the researcher. In addition, every firm's log age is a regressor.

The share of foreign equipment in total equipment κ^f is available for 1986 through 1995. The share of foreign intermediate purchases in total intermediate inputs μ^f is reported from 1996 to 1998. Stacking the observations accordingly identifies $\beta_K \gamma_K$ and $\beta_M \gamma_M$ in the respective subperiods. Section 4.2 (*Foreign Input Push*) will discuss the findings on foreign input efficiency in depth, compare the Cobb-Douglas coefficients to estimates under Box-Cox transforms, and argue that even surprisingly high positive estimates for γ_K and γ_M do not yield a strong effect of foreign inputs on overall efficiency.

3.2 Firm-level total factor productivity

Equation (1) is estimated for 27 manufacturing sectors at *nível 50* (similar to the *ISIC3* two-digit level) with ordinary least squares (OLS), firm-fixed effects (FE), and an extended Olley-Pakes algorithm (EOP). OLS does not treat $\omega_{i,t}$ separate from $\epsilon_{i,t}$. FE considers $\omega_{i,t} = \beta_{0,i}$ to be a time-invariant firm-fixed effect. Only EOP treats $\omega_{i,t}$ distinctly. All coefficients are taken to be constant between 1986 and 1998. This yields time-invariant sector-specific weights for the productivity measures.

³Among the firms that dispose of foreign equipment, the average foreign equipment share is about 14.7 percent in *PIA*. Among the firms that use foreign intermediates, the average share of foreign intermediates is 21.6 percent. Sample means are 2.9 and 9.3 percent, respectively. So, the approximation should be quite precise.

⁴ $S_{i,t}$ includes real estate, premises, but also other capital goods such vehicles, computers, and rented or leased capital goods.

A first measure of firm-level *TFP* is Griliches and Mairesse's (1990) approximation

$$\ln TFP-GM_{i,t} = \ln \frac{Y_{i,t} - (M_{i,t}^{dom} + M_{i,t}^{for})}{L_{i,t}^{bl} + L_{i,t}^{wh}} - \sigma \ln \frac{K_{i,t}^{dom} + K_{i,t}^{for} + S_{i,t}}{L_{i,t}^{bl} + L_{i,t}^{wh}} \quad (2)$$

for $\sigma = 1/3$.

For OLS production function estimates, log total factor productivity at the firm level is

$$\ln TFP-OLS_{i,t} = y_{i,t} - \left(\hat{\beta}_K^{ols} k_{i,t} + \hat{\beta}_S^{ols} s_{i,t} + \hat{\beta}_M^{ols} m_{i,t} + \hat{\beta}_{bl}^{ols} l_{i,t}^{bl} + \hat{\beta}_{wh}^{ols} l_{i,t}^{wh} \right). \quad (3)$$

To focus on three measures only, FE productivity measures are not presented in this study.

The third productivity measure log *TFP-EOP* results from an extended (efficiency-choice adjusted) Olley and Pakes estimation procedure, which is derived and applied in Muendler (2004). For this purpose, the productivity index $\omega_{i,t}$ in estimation equation (1) is considered to be

$$\omega_{i,t} = h(I_{i,t}^K, I_{i,t}^S, a_{i,t}, k_{i,t}, s_{i,t}; \kappa_{i,t}^f; \mathbf{D}_t) + \beta_{0,i} + \xi_{i,t},$$

where $\omega_{i,t} = \ln \Omega_{i,t}$ is the log efficiency of firm i at t and taken to be under the management's control, $\beta_{0,i}$ is the firm-specific mean of productivity shocks, and $\xi_{i,t}$ is a serially uncorrelated shock to productivity with mean zero and constant variance across firms in a sector. The function $h(\cdot)$ of firm-level investments and market conditions approximates individual business prospects and firm-level efficiency responses to the competitive environment. The firm's capital is decomposed into equipment $k_{i,t}$ and structures $s_{i,t}$, and so is physical net investment $(I_{i,t}^K, I_{i,t}^S)$. Both $\beta_{0,i}$ and $\xi_{i,t}$ are known to the firm when it chooses variable factor inputs and investment for next period. While entirely known to the firm's management, $\omega_{i,t}$ is unobservable to the researcher.

The first regression equation is

$$y_{i,t} = \beta_{0,i} + \beta_{bl} l_{i,t}^{bl} + \beta_{wh} l_{i,t}^{wh} + \beta_M \gamma_M \mu_{i,t}^f + \beta_M m_{i,t} + \phi(I_{i,t}^K, I_{i,t}^S, a_{i,t}, k_{i,t}, s_{i,t}; \kappa_{i,t}^f, \mu_{i,t}^f; \mathbf{D}_t) + \xi_{i,t} + \epsilon_{i,t}, \quad (4)$$

a firm-fixed effects regression. A polynomial series estimator of fourth-order approximates $\phi(\cdot) \equiv \beta_K \gamma_K \kappa_{i,t}^f + \beta_K k_{i,t} + \beta_S s_{i,t} + h(\cdot)$. While this first step provides consistent estimates for $\beta_{0,i}$, β_{bl} , β_{wh} , $\beta_M \gamma_M$ and β_M , the capital coefficients β_K , $\beta_K \gamma_K$ and β_S are not identified yet.

Variables \mathbf{D}_t that characterize a firm's competitive environment (foreign market penetration, the economy-wide real exchange rate, nominal tariffs, aggregate demand and the annual inflation rate) partly approximate investments

in productivity-relevant assets. The interaction of these variables with the firms' physical investment in equipment and structures is intended to capture both general business prospects and the firms' individual expectations about them. To avoid a simultaneity problem from the fact that market conditions \mathbf{D}_t respond to prevailing productivity, the nominal exchange rate and foreign producer price indices at the sector level are used as instrumental variables to predict foreign market penetration and nominal tariffs. To firms, moves in the nominal exchange rate and innovations in foreign producer costs are largely unforeseeable at the time of their investment in productivity-relevant assets. Section 4.1 will discuss the validity and predictive power of these instruments in detail.

Next, the probability of a firm's survival

$$Pr(\chi_{i,t+1} = 1|\cdot) = P(I_{i,t}^K, I_{i,t}^S, a_{i,t}, k_{i,t}, s_{i,t}; \mathbf{D}_t) \quad (5)$$

is estimated with independent logit functions for the pre-1991 and the post-1991 data, taking into account that the shutdown probabilities may have changed systematically after trade liberalization. I estimate probabilities over a fourth-order polynomial in $(I_{i,t}^K, I_{i,t}^S, a_{i,t}, k_{i,t}, s_{i,t})$ and \mathbf{D}_t .

Table 1 summarizes logit and probit estimates of survival probabilities for the sample as a whole. When distinguishing by sector, the logit model (correlation coefficient .256) slightly outperforms probit (.249) and is kept subsequently. An elevated (depreciated) real exchange rate results in more protection and thus a higher survival likelihood. Coefficients on market penetration and tariffs are not significant in the baseline regressions (columns 1, 2, 4, and 5). When added, an indicator for exporting status commands a highly significant, positive coefficient (columns 3 and 6). Exporters are more likely to survive. The inclusion of exporting status also makes the coefficient on tariffs significant. However, that sign becomes implausibly negative and points to an omitted variable: Firm-level productivity. Productivity is negatively correlated with tariffs but positively related to survival and exporting status. At this stage, productivity remains to be estimated and the current survival approximation serves as an intermediate step to that end. Consequently, exiting behavior and other aspects of turnover will be revisited in section 4.3 once productivity estimates are available.

A third-order polynomial expansion approximates the expectation of a survivor's productivity $\omega_{i,t+1}$ one period in advance

$$\sum_{m=0}^3 \sum_{n=0}^{3-m} \beta_{m,n} (\hat{P})^m (\hat{h})^n \approx \int_{\underline{\omega}(k_{i,t}, s_{i,t}, \mathbf{D}_t)}^{\omega_{i,t+1}} \frac{f(\omega_{i,t+1}|\omega_{i,t})}{Pr(\chi_{i,t+1} = 1|\cdot)} d\omega_{i,t+1},$$

Table 1: SURVIVAL PROBABILITIES

	Logit			Probit		
	86-90	92-98	89-98 ^a	86-90	92-98	89-98 ^a
	(1)	(2)	(3)	(4)	(5)	(6)
Real exch. rate (USD) ^b	5.255 (.39)	1.13 (.507)	2.301 (.369)	2.322 (.169)	.565 (.223)	1.005 (.161)
Foreign mkt. penetration	.307 (1.136)	-.4 (.615)	-.474 (.551)	.138 (.499)	-.172 (.271)	-.198 (.246)
Nominal tariff	.529 (.308)	-.446 (.738)	-.667 (.263)	.233 (.132)	-.24 (.327)	-.342 (.124)
CPI inflation rate	-.031 (.005)	.082 (.017)	-.016 (.007)	-.014 (.002)	.039 (.007)	-.008 (.003)
$\iota(\text{Exporter})$			.558 (.083)			.246 (.036)
Observations	25,783	23,627	28,932	25,783	23,627	28,932
Outcome correlation ^c		.256			.249	

^aExporting status observed since 1989.

^bAnnual. Based on *IPA-OG* and US producer price index.

^cCorrelation between predictions (zero to one) and outcomes (either zero or one).

Further regressors: Log age, log capital stock, net investment, constant and second to fourth-order polynomial terms (not reported).

where $\underline{\omega}(k_{i,t}, s_{i,t}, \mathbf{D}_t)$ is the minimal productivity realization that a firm with capital $k_{i,t}$ and $s_{i,t}$ tolerates to stay in business under market conditions \mathbf{D}_t . The \hat{P} term in the polynomial expansion is the logit-predicted survival likelihood. The unknown productivity component \hat{h} results from $\hat{h}(\cdot) = \hat{\phi}(\cdot) - (\beta_K \hat{\gamma}_K) \kappa_{i,t+1}^f + \hat{\beta}_K k_{i,t+1} + \hat{\beta}_S s_{i,t+1}$. These considerations give rise to the third estimation equation

$$\begin{aligned}
z_{i,t+1} - \hat{\beta}_{0,i} - \hat{\beta}_{bl} l_{i,t+1}^{bl} - \hat{\beta}_{wh} l_{i,t+1}^{wh} - \hat{\beta}_{\mu} \mu_{i,t+1}^f - \hat{\beta}_M m_{i,t+1} \\
= \beta_{\kappa} \kappa_{i,t+1}^f + \beta_K k_{i,t+1} + \beta_S s_{i,t+1} + \sum_{m=0}^3 \sum_{n=0}^{3-m} \beta_{m,n} (\hat{P})^m (\hat{h})^n + \eta_{i,t+1}.
\end{aligned} \tag{6}$$

Non-linear least squares are applied, using estimates from firm-fixed effects regressions as starting values. This last step yields consistent estimates for β_K , $\beta_K \hat{\gamma}_K$ and β_S .

Table 2 lists EOP production function estimates for the five sectors with most firm-year observations. The efficiency effect of foreign inputs is mostly not significantly different from zero. When significant, foreign equipment exhibits a negative efficiency effect in two out of the three sectors in table 2. This

Table 2: PRODUCTION FUNCTION ESTIMATES (EOP)

Output regressions	Machinery (08)	Wood & furniture (14)	Textiles (22)	Plant products (26)	Food & beverages (31)
Log blue-coll. empl.	.396 (.025)	.426 (.026)	.396 (.025)	.347 (.021)	.386 (.029)
Log white-coll. empl.	.230 (.018)	.156 (.014)	.150 (.018)	.219 (.017)	.195 (.016)
Foreign eqpm. share	.073 (.099)	-.299 (.071)	.138 (.043)	-.243 (.101)	-.044 (.086)
Log equipment	.013 (.016)	.175 (.019)	.030 (.016)	.081 (.018)	.066 (.014)
Log structures	.077 (.017)	.060 (.016)	.079 (.016)	.058 (.023)	.039 (.013)
Foreign intm. share	.114 (.575)	.262 (.239)	-.532 (.277)	-.223 (.21)	-.129 (.268)
Log intermediates	.228 (.015)	.229 (.013)	.322 (.019)	.244 (.013)	.211 (.012)
Foreign market pen.	-391.252 (713.367)	-529.533 (306.53)	1008.876 (419.31)	85.044 (305.721)	-1945.13 (547.761)
Nominal tariff	-19.154 (74.215)	-50.555 (30.249)	97.281 (41.34)	14.023 (30.431)	-193.01 (54.776)
Log aggr. demand	307.473 (95.159)	137.578 (47.621)	289.411 (66.741)	65.781 (69.821)	-115.13 (80.881)
Observations	2,695	2,835	3,260	2,764	3,432

Data: Pesquisa Industrial Annual 1986-1998. Standard errors from 200 bootstraps.

Not reported: Log age, net investment, real exchange rate, inflation rate, higher-order polynomial terms.

suggests that the mean firm may not succeed in putting more expensive foreign equipment to sufficiently effective use during the sampling period.

Only time but no cross-sectional variation identifies the coefficients on foreign market penetration and tariffs in the output regressions within each sector. This results in erratic estimates. As was the case with turnover estimation, the effect of competition variables on productivity should be revisited. Section 4.1 will provide a cross-sectional time-series analysis once consistent estimates of productivity change are at hand. Section 4.2 discusses the coefficient estimates on foreign equipment and foreign intermediate inputs.



Data: Firm-level productivity in 27 manufacturing sectors in *PIA* from EOP estimates, compared to Log *TFP* estimates for Brazil by Bugarin, Ellery Jr., Gomes and Teixeira (2002).

Figure 3: **Log *TFP* and labor productivity in manufacturing**

For EOP production estimates, firm-level log *TFP* is

$$\ln TFP-EOP_{i,t} = y_{i,t} - \bar{\beta}_J - \left(\hat{\beta}_K k_{i,t} + \hat{\beta}_S s_{i,t} + \hat{\beta}_M m_{i,t} + \hat{\beta}_{bl} l_{i,t}^{bl} + \hat{\beta}_{wh} l_{i,t}^{wh} \right). \quad (7)$$

The average firm-fixed effect $\bar{\beta}_J \equiv \sum_{j \in \mathcal{S}} \beta_{0,j} / J$ eliminates confounding time-invariant demand conditions from $\ln TFP-EOP_{i,t}$.

Price is under a firm's control in imperfectly competitive markets. To address this issue, Klette and Griliches (1996) argue that, under monopolistic competition and for a constant elasticity of substitution, aggregate demand can serve as a control variable in the regression. However, the effect of aggregate demand on endogenous efficiency choice cannot be separated from its effect on price setting (Muendler 2004). I therefore remove only the time-invariant demand conditions in sector \mathcal{S} from $\ln TFP-EOP_{i,t}$ by subtracting the average firm-fixed effect $\bar{\beta}_J$ at this stage. Subsequent regressions control for aggregate demand.

Foreign inputs are only known for certain subperiods. So, input efficiency estimates cannot be subtracted from any of the three productivity measures. Subsequent regressions will therefore also include foreign inputs as regressors.

Figure 3 illustrates how *TFP* evolves in the aggregate of all 27 manufacturing sectors between 1986 and 1998. Except for a larger drop during the recession in the late eighties and the subsequent recovery, changes are small

in general. At its trough, log *TFP* drops to .981 in 1990, but recovers and reaches 1.028 by 1998, roughly a five-percent increase over 8 years. Bugarin et al. (2002) report similar, though more volatile aggregate *TFP* figures for Brazilian industry. Cavalcanti Ferreira and Rossi (2003) find no productivity drop during the 1988-90 recession and a more pronounced labor productivity increase during the 1990s. The present study is the only one to employ an extensive firm-level sample. Most previous studies on Brazilian industry consider labor productivity. As figure 3 shows, labor productivity increases more strongly than *TFP* during the 1990s (from .986 to 1.053) because firms raise their capital stock.

The extended Olley and Pakes (EOP) estimation procedure provides a coherent framework to obtain productivity estimates and offers first evidence on the workings of the three channels (*Competitive Push*, *Foreign Input Push*, *Competitive Elimination*). Dismantled trade barriers accelerate *Competitive Elimination* and survival probabilities drop. The contribution of this effect to overall productivity remains to be evaluated. The efficiency effect of foreign inputs is mostly insignificant, at times negative, and suggests only a small contribution of the *Foreign Input Push* to overall productivity. The *Competitive Push* through imports in product markets proved difficult to evaluate on a sector-specific basis since only time variation could provide identification. To draw more definitive conclusions, the following section revisits the three channels individually and mutually exclusively now that consistent productivity estimates are available.

4 Trade-induced Productivity Change

How does trade liberalization affect productivity? Do firms advance to best practice? If so, do foreign inputs contribute to the convergence? Do managers push their firms' efficiency? Or does productivity improve primarily because the least competitive firms are shaken out? Questions like these are related to three channels of trade effects on productivity: (1) A *Competitive Push*, (2) a *Foreign Input Push*, and (3) *Competitive Elimination*. An adequate way to evaluate the effects of trade on productivity seems to be a counterfactual approach. How would productivity have evolved in the absence of any of the three channels?

Subsection 4.1 investigates whether reduced trade barriers exert a positive effect on efficiency because of fiercer competition in the product market (*Competitive Push*). Subsection 4.2 (*Foreign Input Push*) revisits the direct effect of foreign inputs on productivity. Subsection 4.3 analyzes to what degree inefficient firms are shaken out (*Competitive Elimination*) and sheds light on the

question whether more efficient firms become exporters. Subsection 4.4 discusses briefly the effects of potential further channels. The following section 5 will compare the three primary channels, posing the counterfactual that no trade liberalization was undertaken. The *Competitive Push* (1) stands out as the most important channel.

4.1 Channel 1: Competitive Push

Theoretical work posits that increased foreign competition can foster product and process innovation (Boone 2000) or the adoption of new technologies (Yeaple 2003). Foreign competition may also end the ‘quiet life’ of managers and allow firms to enforce higher efficiency (Hermalin 1992, Schmidt 1997). The counterfactual question is: What would firm-level productivity have looked like had there not been an increase in competitive pressure due to foreign imports, or the threat of more foreign imports?

To find an answer, I regress the change in firm-level productivity on two variables related to foreign competition: the nominal tariff in the firms’ respective output markets and the penetration of their markets with foreign imports. Market penetration proxies the level of non-tariff barriers in Brazil, while nominal tariff levels capture the effect of tariff barriers directly. Foreign penetration is measured as the share of imports per absorption in a given market. To separate this channel from the *Foreign Input Push* and *Competitive Elimination*, I include foreign input variables as regressors and consider productivity change, rather than levels, among year-over-year survivors.

However, there are econometric concerns. Market penetration and low tariff barriers may not only induce firms to strive for higher productivity. Causation can also run in the opposite direction. Consider tariffs. The Brazilian government justified its repeal of trade barriers with the intention to instill efficiency change through foreign competitive pressure and to create checks on the pricing power of concentrated industries. If the government pursued these objectives, it must have applied lower tariffs to sectors with slow efficiency change. This introduces a positive correlation between *TFP* change and tariff levels.⁵ Second, take market penetration. When barriers to imports fall, the least efficient sectors are likely to attract the strongest influx of competing imports. In other words, low productivity performance may cause high market penetration, which brings about a negative correlation between *TFP* change and market penetration.

⁵Common political-economy arguments would suggest the converse that less efficient sectors with the largest losses at stake lobby successfully for higher protection. Either way, an endogeneity problem calls for resolution.

Instrumental variables (IVs) can remedy both sources of endogeneity and simultaneity. Foreign market penetration not only depends on tariffs and competitors' productivity but also responds to a country's terms of trade. The real exchange rate fluctuates considerably over the period 1986 to 1998 and is thus an important factor for the relative price of imports. Certain components of the real exchange rate are exogenous variables in the sense that they affect foreign firms' entry decision (and the government's tariff choice) but Brazilian firms are unable to anticipate them at the time of their productivity investment.

The real exchange rate is decomposed here into several components, each serving as an instrument. Baseline IVs are the nominal exchange rate relative to the US dollar, an average sector-specific European and an average sector-specific US-Canadian producer price index (using Brazilian imports as weights).⁶ Revenga (1992) employs similar IVs in the context of foreign trade and labor markets.

Nominal exchange rates are hard to predict in economic models, and Brazilian firms are likely not able to forecast the US dollar exchange rate well. This makes the nominal exchange rate a valid instrument. Foreign producer prices proxy current production costs among foreign competitors. For Brazilian managers, the multitude of factors that affect producer costs abroad are difficult to anticipate. These factors range from changes to individual competitors' efficiency, to wage levels and rental rates, to macroeconomic shocks. So, Brazilian firms' *TFP*-relevant decisions are likely taken before shocks to foreign producer costs occur, which makes contemporaneous foreign producer prices valid instruments.

There are two endogenous variables, tariffs and market penetration. Three baseline IVs predict them: the nominal exchange rate, the European and the US-Canadian price index. Joint F tests on the IVs in the first-stage regressions refute the hypothesis that these are weak instruments (with F test statistics orders of magnitude above 10, Staiger and Stock 1997).

Table 3 shows how survivors change efficiency in response to their competitive environment. Only regressions of the *changes* (first differences) in log *TFP* can separate the *Competitive Push* on survivors from *Competitive Elimination* through sample exit. A difference-in-difference analysis confirms that exiting firms have lower productivity on average. Fiercer foreign competition is likely to bring about more exits. So, level regressions would confuse the

⁶More than a quarter of Brazilian imports between 1986 and 1998 are US products. Trade weights are based on the year 1995. PPI series come from BLS for the US and from SourceOECD's *Indicators of Industry and Services* for all other OECD member countries. For the non-OECD countries among Brazil's major 25 trading partners WPI and CPI indices from www.globalfindata.com are used.

two channels and inappropriately boost the estimates. Unobserved managerial ability, product quality and output composition, and any sector-specific constants such as potentially differing units of measurement, are likely to affect a firm's *TFP*. Consequently, a fixed-effects model is estimated throughout and standard errors are corrected accordingly.

Table 3 summarizes the regression results for the log *TFP-EOP* measure as dependent variable. Column 1 reports the fixed-effects (FE) estimation in the absence of instrumentation. The two-stage least-squares FE (2SLS-FE) approach is synthesized in columns 2 through 4. For comparisons, column 5 presents a plain FE regression with the log *TFP-GM* measure (absent instrumentation). The dependent variable in all regressions is the first difference in log *TFP* (except, of course, for the first-stage IV regressions in columns 3 and 4). In general, a substantial random component appears to drive changes to log *TFP*. Low R^2 values indicate that both firm-level and market-level regressors predict only a small share of the changes in log *TFP*.

Both the nominal *ad valorem* tariffs on final goods and the market penetration rates with foreign goods are fractions, measured on a scale from zero to one (or beyond in the case of tariffs). Lower tariffs induce firms to raise efficiency, as does higher market penetration (column 1). The effects are significant even when endogeneity and simultaneity issues are not addressed. However, as argued above, there is likely a positive bias in the tariff coefficient (bad efficiency performers are targeted with low tariffs) and a negative bias in the coefficient on market penetration (inefficient sectors are easy game for foreign competitors). In fact, 2SLS-FE estimates raise the estimates in absolute value (pushing the tariff coefficient further into the negative and the penetration coefficient up, column 2). This confirms the suspected endogeneity. The same suspected positive bias in tariffs and negative bias in market penetration can be detected in level regressions. Estimates would be more favorable when inferring productivity from a simple log *TFP-GM* calculation (not instrumenting in the present Δ log *TFP-GM* regression, column 5).

Considering the 2SLS-FE estimates, a reduction of nominal tariffs by 10 percentage points (.1) induces firms to increase log *TFP* by .061. An increase in foreign market penetration by 1 percentage point (.01) raises log *TFP* by another .035. Log *TFP* is about 8.08 on average across all sectors and years. So, a reduction of nominal tariffs by 10 percentage points pushes log *TFP* (EOP) by three quarters of a percent $(.061/8.08) * 100$. At the five-year horizon, 2SLS-FE regressions cease to yield significant coefficients. In plain FE regressions, however, changes in tariffs have almost identical efficiency effects. Regressions of 5-year changes on 5-year changes show that a 10-percentage-point drop in tariffs (.1) is associated with an increase of .065 in log *TFP*

Table 3: FOREIGN COMPETITION AND PRODUCTIVITY CHANGE

	FE (EOP)	2SLS-FE (EOP)		FE (GM)	
	$\Delta \ln TFP$	$\Delta \ln TFP$	Tariff	M.Pen.	$\Delta \ln TFP$
	(1)	(2)	(3)	(4)	(5)
Nominal tariff	-.132 (.027)	-.611 (.072)			-.270 (.051)
Market penetration	1.090 (.149)	3.494 (.558)			1.565 (.289)
κ^f	-.056 (.029)	-.109 (.03)	-.085 (.006)	.001 (.001)	-.281 (.057)
μ^f	.090 (.035)	.081 (.04)	.069 (.008)	.028 (.001)	.418 (.068)
$\iota(\text{medium } L^{tot})^a$	.160 (.029)	.162 (.03)	-.002 (.006)	-.003 (.001)	.198 (.057)
$\iota(\text{big } L^{tot})^a$	.185 (.031)	.186 (.031)	-.013 (.006)	-.005 (.001)	.172 (.059)
$\iota(\text{medium cap.})^b$	-.091 (.022)	-.077 (.022)	.006 (.005)	.0002 (.0009)	.021 (.043)
$\iota(\text{big cap.})^b$	-.101 (.024)	-.077 (.025)	.003 (.005)	-.001 (.001)	.062 (.047)
Sector demand ^c	-.269 (.013)	-.347 (.018)	-.054 (.003)	.018 (.0005)	-.467 (.025)
FDI flow ^d	-.039 (.008)	-.062 (.009)	-.047 (.002)	-.0003 (.0003)	-.116 (.016)
Cum. FDI ^d	.020 (.007)	.059 (.009)	.037 (.001)	-.006 (.0003)	.049 (.014)
Nom. exch. rate (USD)			.583 (.015)	.075 (.003)	
CPI Brazil			-.376 (.014)	-.057 (.003)	
PPI EU			-.218 (.019)	.072 (.004)	
PPI North America			.035 (.019)	-.156 (.004)	
Obs.	30,841	30,841	30,841	30,841	30,841
R^2 (within)	.021	.002	.860	.595	.032
F (instruments)			1730.7	817.9	

^aMedium: ($30 \leq L_{i,t}^{tot} < 300$), big: ($L_{i,t}^{tot} \geq 300$).

^bMedium: $K_{i,t} + S_{i,t}$ in middle tercile of all firms in a year, big: in upper tercile.

^cSector-wide sales in *PIA*, augmented by foreign market penetration.

^dBillion USD per sector. Cumulated FDI is end-of-year stock of invested foreign capital. Further regressors: Age, Age² (not reported).

(table 4, column 4). Given that total *TFP* change in Brazilian manufacturing was only about five percent throughout the nineties, .75 percent are noticeable. A careful counterfactual simulation will follow in section 5 and confirm that the *Competitive Push* has a detectable impact on overall *TFP* in Brazilian manufacturing.

To isolate the effect of foreign competition from possibly confounding effects, firm-level variables such as foreign inputs and indicators for relative firm size are in the *Competitive Push* regressions. Schor (2003) analyzes a similar sample of Brazilian manufacturers, controls for channels 1 and 2 by using final-good and input tariffs separately in log *TFP* regressions, and finds a slightly stronger coefficient on input tariffs than on final-good tariffs. To keep the two channels separate here, foreign inputs are included as covariates. Estimates suggest that firms that start to use more foreign inputs suffer a slowdown in productivity in the subsequent year (table 3). They face implementation costs, may need to retrain workers and carry out adjustments to the production process (compare subsection 4.2).

The stock of sector-wide invested foreign capital correlates positively with productivity increases at the firm-level. Foreign investment (FDI) directed to a sector as a whole may force each individual firm to improve efficiency because foreign-owned domestic competitors are likely to become more productive with foreign capital. So, FDI may work like a substitute for trade liberalization. However, it takes USD 1 Billion to raise log *TFP* by .062—an increase that a tariff reduction by 10 percentage points (.1) can also achieve. The invested foreign capital stock in Brazilian manufacturing totalled USD 30 Billion in 1998. In this light, an FDI inflow of USD 1 Billion in a single sector would be substantial. In addition, FDI flows seem to have an offsetting negative effect on productivity. This may be because FDI to foreign-owned domestic competitors also reduces the market penetration of foreign firms that export to Brazil (column 4). Aitken, Hanson and Harrison (1997) find evidence of positive efficiency spillovers from multinational companies' FDI to domestic manufacturers in Mexico. However, Aitken and Harrison (1999) cast doubt on the generality of this finding, showing that foreign investment negatively affects the productivity of domestically owned plants in Venezuela. The mixed coefficients on cumulated FDI and FDI flows in Brazil may point either way.

In the first stage of the instrumental variable estimation (columns 3 and 4), fixed-effects regressions are run using all observations. This makes the regressions in columns 3 and 4 weighted ones. The tariff cannot be used as a predictor of market penetration (column 4). If included, order conditions would fail and the system would not be identified. Separate regressions show that market penetration drops .74 percentage points on average across all sectors when

Table 4: FURTHER RESULTS ON FOREIGN COMPETITION AND LOG *TFP* CHANGE

	$\Delta_{1yr} \ln TFP$			$\Delta_{5yrs} \ln TFP$		
	<i>EOP</i>	<i>OLS</i>	<i>GM</i>	<i>EOP</i>	<i>OLS</i>	<i>GM</i>
	(1)	(2)	(3)	(4)	(5)	(6)
	2SLS-FE					
Tariff ^a (Level, Δ_{5yrs})	-.611 (.072)	-.525 (.079)	-1.552 (.141)	-4.585 (3.132)	-3.136 (2.922)	-2.550 (5.842)
Mkt. Pen. ^b (Level, Δ_{5yrs})	3.494 (.558)	3.991 (.608)	5.742 (1.087)	6.449 (5.839)	4.494 (5.446)	1.913 (10.891)
	FE					
Tariff (Level, Δ_{5yrs})	-.132 (.027)	-.110 (.029)	-.270 (.051)	-.648 (.259)	-.439 (.261)	-.629 (.567)
Mkt. Pen. (Level, Δ_{5yrs})	1.090 (.149)	1.132 (.163)	1.565 (.289)	-.656 (.365)	-.765 (.367)	-2.232 (.798)
Obs.	30,841	30,841	30,841	3,856	3,856	3,856

^aThe *F* statistics on instruments for tariffs are 1730.7 and 56.1, respectively.

^bThe *F* statistics on instruments for market penetration are 817.9 and 30.3, respectively.

Further regressors: Age, Age², κ^f , μ^f , $\iota(\text{medium } L^{tot})$, $\iota(\text{big } L^{tot})$, $\iota(\text{medium cap.})$, $\iota(\text{big cap.})$, sector demand, FDI flow, and Cumulated FDI (not reported).

tariffs are raised by 10 percentage points.

Findings hardly change for the log *TFP-OLS* measure (from straight-forward production function regressions on the unbalanced panel). Table 4 reports coefficients on tariffs and market penetration for a log *TFP-OLS* productivity measure and contrasts them with estimates for the log *TFP-EOP* measure (columns 2, 1 and 5, 4). In fact, *t* tests consistently fail to reject the hypothesis that coefficients for log *TFP-EOP* and log *TFP-OLS* measures are identical. The rough log *TFP-GM* measure yields some significantly higher coefficient estimates in absolute value. However, the magnitude of competitive effects on productivity is very similar across all three *TFP* measures.

The consistency of 2SLS estimates depends on the validity of the proposed IVs. Table 5 documents a procedure to test for the validity of additional instruments. Departing from a regression that includes only the baseline instruments (the nominal US dollar exchange rate, the EU producer prices and the US-Canadian producer prices), I insert additional instruments and perform Hausman (1978) tests for overidentification. Brazilian domestic inflation is more predictable for firms and could possibly have an impact on managers' efficiency choice. It is therefore not taken as a baseline IV, notwithstanding its

Table 5: FOREIGN COMPETITION AND PRODUCTIVITY CHANGE, OVER-IDENTIFICATION TESTS FOR VALIDITY OF INSTRUMENTS

2SLS-FE (EOP)	Base ^a	Add	Add	Add	Add
	(1)	<i>CPI_{Brazil}</i> (2)	<i>WPI_{World}</i> (3)	<i>PPI_{OECD}</i> (4)	<i>CPI_{Arg.}</i> (5)
Nominal tariff	-.594 (.073)	-.611 (.072)	-.512 (.065)	-.612 (.071)	-.240 (.062)
Market penetration	3.762 (.577)	3.494 (.558)	3.558 (.569)	4.033 (.522)	2.776 (.563)
Obs.	30,841	30,841	30,841	30,841	30,841
$\hat{\chi}^2$		3.677	16.799	.878	-91.704
$Pr(\chi^2_{12} > \hat{\chi}^2)$		.989	.157	1	

^aBaseline instrumental variables: Nom. exch. rate (USD), PPI EU, PPI North America
Further regressors: Age, Age², κ^f , μ^f , $\iota(\text{medium } L^{tot})$, $\iota(\text{big } L^{tot})$, $\iota(\text{medium cap.})$, $\iota(\text{big cap.})$, sector demand, FDI flow, and Cumulated FDI (not reported).

importance for the real exchange rate. However, overidentification tests fail to reject its validity by a large p value (column 2). One might suspect that Brazilian manufacturers were able to anticipate well the aggregate price level of major trading partners such as Argentina's (Brazil's number two source country after the US). In fact, overidentification tests show that Argentina's CPI level is not a well-behaved instrument (the χ^2 test statistic takes a non-permissible negative value, column 5). Neither a mixed index of annual and sector-specific wholesale, producer and consumer price indices for Brazil's major 25 import-source countries (column 3) nor the sector-specific producer price index of all OECD countries among Brazil's major 25 import sources (column 4) change point estimates significantly. This vindicates the likely validity of the baseline instruments.

Had there not been an increase in competitive pressure due to foreign imports, Brazilian manufacturers would have continued their 'quiet lives' and productivity would have improved more slowly.

4.2 Channel 2: Foreign Input Push

How would firm productivity have evolved if firms had not been able to install foreign equipment or to use foreign intermediates to the same extent? Supposedly, foreign inputs exhibit higher quality and efficiency.

Under a logarithmic approximation, the terms $\beta_K \gamma_K \kappa_{i,t}^f$ and $\beta_M \gamma_M \mu_{i,t}^f$

Table 6: FOREIGN INPUT EFFICIENCY

Sector counts	OLS (1)	EOP ^a (2)	FE (3)
<i>t</i> tests for non-zero coefficients			
$\beta_K \gamma_K \neq 0$	13 (11) of 27	8 (3) of 27	3 (1) of 27
$\beta_M \gamma_M \neq 0$	11 (7) of 27	1 (1) of 27	8 (4) of 27
<i>F</i> tests for efficiency differences			
$\beta_K \gamma_K \neq \beta_K$	11 (9) of 27	8 (2) of 27	4 (1) of 27
$\beta_M \gamma_M \neq \beta_M$	11 (3) of 27	3 (1) of 27	11 (2) of 27
Average ^b γ_K and γ_M			
Mean $\widehat{\beta_K \gamma_K} / \widehat{\beta_K}$	5.71 (13 of 27)	-4.73 (3 of 27)	-8.36 (1 of 27)
Mean $\widehat{\beta_M \gamma_M} / \widehat{\beta_M}$	.875 (11 of 27)	8.30 (1 of 27)	.051 (8 of 27)

^aVariance and covariance estimates from 200 bootstraps. Wald tests instead of *F* tests.

^bSectors included if $\beta_K \gamma_K$ and β_K , or $\beta_M \gamma_M$ and β_M , significantly different from zero at .95 level.

Data: PIA 1986-98, deflated with IPA-OG and import-weighted foreign PPI series.

Figures in (brackets) are counts of positive estimates $\widehat{\beta_K \gamma_K} > 0$ or $\widehat{\beta_M \gamma_M} > 0$. To find upper bounds on sector counts, significance levels are kept at .95 and not adjusted for repeated testing.

measure the differential effect of foreign inputs on output. When included in Cobb-Douglas production functions, these terms capture the efficiency differences between foreign and domestic inputs that would otherwise be attributed to overall *TFP*. β_K and β_M are the elasticities of output with respect to total equipment and total intermediate goods. $(1 + \gamma_K)$ and $(1 + \gamma_M)$ are the efficiency premia of foreign inputs, and κ^f and μ^f are the shares of foreign inputs in the respective totals. κ^f is available for the years 1986 through 1995, while μ^f is observed from 1996 until 1998. An accordingly stacked system identifies the coefficients (see section 3.1).

Table 6 summarizes in how many of the 27 sectors the coefficients on foreign equipment shares κ^f and foreign intermediate goods shares μ^f significantly differ from zero (*t* tests) and from the coefficients on total equipment k and total intermediate inputs m (*F* tests). These coefficients on κ^f and μ^f are estimates for $\beta_K \gamma_K$ and $\beta_M \gamma_M$.

The *F* tests (Wald tests in the case of EOP) check the null hypotheses that $\beta_K \gamma_K = \beta_K$ and $\beta_M \gamma_M = \beta_M$. Whereas OLS estimation of the pro-

duction function (column 2) tends to suggest frequent efficiency differences between foreign and domestic inputs, EOP estimation does not (column 3). The reason is that OLS estimation fails to remove both firm-fixed effects and endogenous policy responses from firm-level productivity. In fact, omitting the instrumental-variable prediction of competition variables from productivity estimation (section 3.2) would result in very different estimates for foreign inputs. Column 4 shows that fixed-effects estimation of the production function ($\omega_{i,t} = \beta_{0,i}$) also identifies fewer efficiency differences between foreign and domestic inputs than OLS. A common finding is, however, that foreign inputs are not always employed more efficiently than domestic inputs. The coefficients on κ^f and μ^f turn negative in several sectors with significant estimates.

Efficiency estimates of foreign equipment ($\beta_K\gamma_K/\beta_K$) and foreign intermediate inputs ($\beta_M\gamma_M/\beta_M$) are high in absolute value at the extremes and not stable across estimation procedures. Under EOP estimation, significant γ_K estimates vary between -9.4 and -1.8 (mean -4.7), the only significant γ_M estimate is 8.3 . This means that, in this one sector with a given factor elasticity of intermediate goods, foreign intermediates are more than nine times more effective in producing output than domestic inputs. Under OLS estimation, the distribution is more volatile and γ_K varies between -11.5 and 13.9 (mean 5.7), γ_M takes values between -1.2 and 4.2 (mean $.9$). Negative coefficients may be interpreted as evidence that the average firm in a given sector fails to adjust its surrounding production process accordingly and cannot immediately realize the potential benefits of high-quality equipment or intermediate inputs.

Table 7 summarizes mean log *TFP* and the effect of foreign inputs in the two sectors with the highest positive significant $\beta_K\gamma_K$ estimates (10, 24) and the sector with the highest positive significant $\beta_M\gamma_M$ estimate (28). The figures show that foreign input efficiency contributes only little to productivity. Take foreign equipment in the electrical-equipment sector (10) as an example. Between 1986 and 1990, these manufacturers invested strongly in foreign equipment and pushed $\beta_K\gamma_K\kappa^f$ from $.004$ to $.014$. Without that $.010$ push, log *TFP* would have fallen to 8.72 by 1990 but foreign equipment stopped the fall at 8.73 . This is less than a $.2$ percent contribution to overall log *TFP* for one of the strongest positive $\beta_K\gamma_K$ effects in the sample. Similar calculations can be made for other sectors and periods. Differential foreign input efficiency neither seems to serve as a break in times of falling productivity nor as a push in times of rising log *TFP*. Counterfactual simulations in section 5 confirm that foreign inputs do not exert noticeable benefits beyond their price of acquisition.

Foreign machines of high quality tend to sell at a price premium over domestic counterparts, and firms need to put foreign machines to more efficient uses than domestic ones in order to avoid a productivity loss. Five sectors ex-

Table 7: EFFICIENCY CONTRIBUTION OF FOREIGN INPUTS

EOP	10 <i>Electrical eqpm.</i>		24 <i>Footw. & leather</i>		28 <i>Dairy products</i>	
	log <i>TFP</i>	Input	log <i>TFP</i>	Input	log <i>TFP</i>	Input
	(1)	(2)	(3)	(4)	(5)	(6)
		$\beta_K \gamma_K \cdot \kappa^f$		$\beta_K \gamma_K \cdot \kappa^f$		$\beta_K \gamma_K \cdot \kappa^f$
1986	8.857	.004	9.314	.002	11.263	-.005
1990	8.730	.014	8.985	.010	10.811	-.026
1992	9.203	.020	9.198	.018	10.914	-.028
1995	9.327	.044	9.029	.042	10.825	-.047
		$\beta_M \gamma_M \cdot \mu^f$		$\beta_M \gamma_M \cdot \mu^f$		$\beta_M \gamma_M \cdot \mu^f$
1996	9.693	.025	8.949	.133	10.867	.071
1998	9.614	.032	9.046	.111	11.032	.196

Foreign inputs in the two sectors with the highest positive significant $\beta_K \gamma_K$ estimates (10, 24) and the sector with the highest positive significant $\beta_M \gamma_M$ estimate (28).

Data: PIA 1986-98, deflated with IPA-OG and import-weighted foreign PPI series.

hibit significantly negative estimates of $\beta_K \gamma_K$ under EOP. These estimates may be evidence that the mean firm in those sectors fails to effectively implement foreign inputs in the short term. Technology adaption takes time because of factor complementarities, learning effects and necessary production rearrangements. Similar arguments have been advanced to explain the productivity slowdown in industrialized countries in periods of technology adoption.

Firms may learn over time how to integrate new foreign equipment into their production. To test for this type of learning, one can split κ^f into recent-year investment and the lagged κ^f level, and re-estimate production. In all but four of the 27 sectors, the coefficient on the lagged κ^f level is lower (either more negative or less positive) than the coefficient on recent-year investment. So, older vintages of foreign equipment seem to hamper productivity, whereas firms' more recent investments in foreign equipment tend to affect productivity positively or at least not as strongly negatively. In other words, firms seem to learn to implement foreign equipment more effectively over time.

Firms may benefit from embodied technology when acquiring foreign goods. That is, foreign drilling machines or turning lathes are supposed to do more than just process a workpiece. They are thought to be essentially different from their domestic counterparts under this hypothesis. If it is true, foreign inputs should enter the production function separately and interact with other factors in a different way than domestic inputs. However, foreign inputs are often zero.

In fact, 80.4 percent of all firms in 1986-1995 dispose of no foreign machines, and 56.9 percent of all firms in 1996-1998 use no foreign intermediate inputs. So, standard production functions cannot be estimated. To accumulate more evidence, earlier drafts of this paper used a Box-Cox transformation for both types of foreign inputs in addition to the modified Cobb-Douglas production function and estimated production functions under accordingly adjusted Olley-Pakes procedures.

Under a Box-Cox transformation, resulting log *TFP* figures were lower and behaved more erratically, while estimates of input efficiency differentials were higher. Under the extreme counterfactual hypothesis that all inputs had to be Brazilian rather than partly foreign, I reassessed firm-level *TFP*. In the case of foreign equipment, for instance, I took the difference $[\hat{\beta}_{K^f}((K_{i,t}^f)^{\hat{\lambda}_K} - 1)/\hat{\lambda}_K + \hat{\beta}_{K^d} \ln K_{i,t}^d] - [\hat{\beta}_{K^d} \ln(K_{i,t}^d + K_{i,t}^f)]$ as a measure for the contribution of foreign equipment efficiency and compared it to the values in columns 2, 4 and 6 of table 7. The number reflected the difference that setting κ^f to zero would make (the most extreme counterfactual possible). However, the relative magnitude of foreign input efficiency was still not high enough to account for substantive *TFP* changes over time. This vindicates current findings and there is little evidence that effects of embodied technology are sources of immediate productivity change.

At the micro-level, to my knowledge only Feenstra et al. (1992) and Fernandes (2003) estimate the effect of inputs on production. Feenstra et al. (1992) distinguish the effect of more inputs of the same type from the effect of a greater range of them in a sample of Korean *chaebol*—albeit not with respect to foreign trade. They detect a positive correlation between their input measure and the change in *TFP*. Using a large sample of Colombian plants, Fernandes (2003) finds that productivity gains are stronger in sectors that use foreign intermediates to a higher degree. However, neither one of the studies reports how much *TFP* change their estimates predict and their findings cannot be compared to those of table 7. Keller (2000) reports for a sample of industries in 8 OECD countries that machinery imports matter but that their impact may be limited conditional on the effect of domestic technology.

Had firms not been able to install foreign equipment or to use foreign intermediates as after trade liberalization, productivity would have evolved largely in the same way. Higher quality or efficiency of foreign inputs likely elevates their price. Moreover, to make appropriate use of new inputs, firms need to embed foreign equipment into the production process and may have to adopt new processes. If they can take such measures only over time, foreign inputs may not create value beyond cost in the short term.

Table 8: TRANSITIONS BETWEEN STATES OF OPERATION BEFORE AND AFTER 1991

Firm		$Pr(\sigma_{i,t+1}|\sigma_{i,t})$				Total
$\sigma_{i,t}$	$\sigma_{i,t+1}$	active exporter (1)	active non-exporter (2)	suspended (3)	extinct (4)	
active						
exporter		86.2 ▷ 88.4	12.4 ▷ 8.3	.8 ▷ .9	.6 ▷ 2.4	100.0
non-exp.		3.7 ▷ 6.9	91.9 ▷ 86.1	1.6 ▷ 2.0	2.8 ▷ 5.0	100.0
suspended		1.9 ▷ 7.6	31.6 ▷ 31.4	57.3 ▷ 42.0	9.2 ▷ 19.0	100.0
extinct		.0 ▷ .0	.0 ▷ .0	.0 ▷ .0	100.0 ▷ 100.0	100.0

Source: Own calculations from observed transitions 1989-98. (Observations of mergers, acquisitions and split-ups treated as missing. Transitions 1990-92 treated as if 1990-91.)

Data: *Pesquisa Industrial Anual*. Firm-level exports from *SECEX*, 1989-1998.

4.3 Channel 3: Competitive Elimination

What would industry turnover have looked like in the absence of trade liberalization? There are many aspects to industry turnover and it has proven hard to link them directly to the trade regime. I propose a new method to evaluate turnover directly: The estimation of Markov probabilities for an active firm's transition between possible states (modes) of operation.⁷

The transition probabilities in table 8 reflect the likely pattern of a Brazilian manufacturer's choice of operation mode between 1989 and 1991 (to the left of the arrows), and between 1991 and 1998 (to the right of the arrows). Data on the exporting status of firms are not available before 1989. There are salient changes in the unconditional turnover probabilities before and after 1991—the mid year of Brazil's trade liberalization. The exit probability of a non-exporter, for instance, rises from 2.8 to five percent.

To evaluate directly how the trade regime influences turnover, transition probabilities are estimated as functions of the market environment and firm characteristics, among them productivity. Unnested, unconditional and unordered multinomial logit (MNL) appears to be an appropriate estimation technique. MNL rests on the assumptions that (i) independence from irrelevant alternatives holds, (ii) neither firms nor the states of operation have specific characteristics beyond a set of observable covariates, and (iii) the covariates capture profit prospects completely so that there is no inherent order-

⁷This estimation principle has been applied to education choice, labor market transitions, patent renewals, replacement investments, fertility and many other dynamic discrete decision processes before (Magnac and Thesmar 2002).

Table 9: MULTINOMIAL LOGIT ESTIMATES OF TRANSITION PROBABILITIES

	$\sigma_{i,t}$ $\sigma_{i,t+1}$	Exporter			Non-Exporter		
		Non-Exp. (1)	Susp. (2)	Exit (3)	Exp. (4)	Susp. (5)	Exit (6)
Nominal tariff ^a		1.957 (.303)	-1.015 (1.176)	-2.680 (.944)	-.234 (.152)	-1.300 (.555)	-1.732 (.482)
Market penetration		.270 (.672)	-1.536 (2.156)	-.540 (1.257)	3.334 (.507)	-.788 (1.553)	2.317 (1.003)
Real exch. rate (USD) ^b		-.781 (.272)	.434 (.831)	-2.751 (.696)	-1.582 (.133)	-.614 (.467)	-2.523 (.387)
$\ln TFP-EOP$		-.081 (.038)	-.232 (.1)	.100 (.068)	.122 (.021)	-.328 (.072)	-.258 (.057)
κ^f		-1.156 (.329)	-.695 (1.221)	-2.171 (.977)	.992 (.236)	-1.107 (1.172)	-1.242 (.839)
μ^f		-1.726 (.519)	-.112 (1.003)	-.056 (.648)	-.011 (.407)	-2.738 (2.445)	.135 (.805)
$\iota(\text{med. } L^{tot})^c$		-1.236 (.456)	-.836 (1.066)	-1.69 (.703)	.861 (.27)	-.181 (.333)	-.971 (.206)
$\iota(\text{big } L^{tot})^c$		-1.826 (.456)	-2.035 (1.082)	-1.945 (.721)	1.532 (.27)	-.700 (.379)	-1.402 (.243)
$\iota(\text{med. cap.})^d$		-1.085 (.284)	-.112 (1.029)	-1.408 (.413)	.651 (.185)	-.322 (.256)	-.172 (.197)
$\iota(\text{big cap.})^d$		-1.511 (.29)	-.047 (1.055)	-1.75 (.436)	1.416 (.188)	-.235 (.314)	-.127 (.24)
Sector demand ^e		-.102 (.086)	.057 (.243)	-.035 (.164)	.194 (.053)	.409 (.171)	.184 (.138)
FDI flow ^f		.049 (.093)	.512 (.223)	.384 (.192)	-.497 (.072)	.205 (.188)	-.113 (.163)
Cum. FDI ^f		.063 (.037)	.013 (.102)	-.22 (.075)	-.034 (.026)	-.084 (.079)	-.143 (.054)
Obs.			11,092			22,814	
Pseudo R^2			.045			.081	
$\hat{\chi}^2$			383.6			1398.8	
$Pr(\chi_{42}^2 > \hat{\chi}^2)$			.0000			.0000	

^aNext year's nominal tariff.

^bAnnual. Based on *IPA-OG* and US producer price index.

^cMedium: ($30 \leq L_{i,t}^{tot} < 300$), big: ($L_{i,t}^{tot} \geq 300$).

^dMedium: $K_{i,t} + S_{i,t}$ in middle tercile of firms in a year, big: in upper tercile.

^eSector-wide sales in *PIA*, augmented by foreign market penetration.

^fBillion USD per sector. Cumulated FDI is end-of-year stock of invested foreign capital. Further regressors: Age and a *constant* (not reported).

ing of the operation modes beyond the information in covariates and no serial correlation in the error term.⁸ Magnac and Thesmar (2002) show that dynamic choice models are generally underidentified. Firm-fixed effects or serial correlation in the error, for instance, can only be estimated at the expense of other restrictions since optimality conditions cannot provide identification for more than one reference firm.

MNL is a natural point of departure. Under the MNL assumptions, a firm's probabilistic choice is

$$Pr(\sigma_{i,t+1} | \sigma_{i,t} = \sigma; \mathbf{x}, \beta_{\mathbb{M}}) = \frac{e^{\beta_{\sigma}' \mathbf{x}}}{\sum_{\varsigma \in \mathbb{M}} e^{\beta_{\varsigma}' \mathbf{x}}},$$

where the choice set \mathbb{M} of operation modes includes four alternatives states $\sigma_{i,t+1}$: to be an exporter, to be a domestically active firm only, to suspend production temporarily, or to exit. The model is estimated independently for the three possible current states $\sigma_{i,t}$: exporter, non-exporter, or temporarily suspended firm.

Table 9 reports results for active firms ($\sigma_{i,t}$: exporter or non-exporter), and table 10 presents the remaining category ($\sigma_{i,t}$: suspended firm). Since probabilities have to sum to unity, the parameter vector β_{σ} is only identified for three choices relative to a fourth choice of reference. Here, the current states of operation ($\sigma_{i,t+1} = \sigma_{i,t}$) are chosen as the respective points of reference. The reference for a non-exporter, for instance, is that the firm remains a non-exporter.

To find the effect of trade on turnover beyond previous channels, I use firm-level log *TFP-EOP* as a regressor of its own. Productivity has the expected effect on turnover. The lower it is, the more likely a firm exits or suspends production (columns 2, 5 and 6 in table 9). Interestingly, log *TFP-EOP* does not significantly affect the exit likelihood of exporters (column 3). Both theory (Melitz 2003, Bernard, Eaton, Jensen and Kortum 2003b, Yeaple 2003) and empirical evidence (Clerides, Lach and Tybout 1998, Bernard and Jensen 1999) suggest that more efficient firms self-select into becoming exporters. The present analysis supports this hypothesis. When productivity is high, non-exporters start exporting more often (column 4) and exporters abandon exporting less frequently (column 1). Table 11 shows that the estimates are similar for log *TFP-OLS*. Incentives for exporting from Brazil hardly changed over the period. So, the positive association of higher productivity with exporting status can be regarded as close to causal: High productivity turns

⁸Ordered logit has the unattractive feature of summarizing the transition likelihood with a single scalar score variable. MNL, on the other hand, allows to distinguish different coefficients of the covariates for different transitions.

Table 10: FURTHER MULTINOMIAL LOGIT ESTIMATES OF TRANSITION PROBABILITIES

	$\sigma_{i,t}$ $\sigma_{i,t+1}$	Suspended Firm			Non-Exporter		
		Exp.	Dom.	Exit	Exp.	Susp.	Exit
		(1)	(2)	(3)	(4)	(5)	(6)
Nominal tariff ^a		-19.311 (4.416)	-8.135 (3.979)	-3.082 (2.478)	-.258 (.175)	-1.300 (.556)	-1.758 (.483)
Δ Tariff ^a					-10.132 (.356)	-1.411 (1.281)	-1.661 (1.333)
Market penetration		.003 (7.382)	2.509 (5.772)	-6.478 (11.352)	5.811 (.549)	-.729 (1.663)	2.842 (1.041)
Δ Mkt. penetration					-10.597 (2.262)	7.206 (7.024)	-4.683 (3.402)
Real exch. rate (USD) ^b		9.303 (3.166)	5.671 (2.736)	-.192 (3.365)	-2.771 (.153)	-.618 (.487)	-2.713 (.43)
$\ln TFP-EOP$		1.106 (.392)	.299 (.339)	-.801 (.366)	.113 (.023)	-.321 (.072)	-.273 (.057)
Obs.				104		22,783	
Pseudo R^2				.357		.12	
$\hat{\chi}^2$						2009.5	
$Pr(\chi_{48}^2 > \hat{\chi}^2)$						.0000	

^aNext year's tariff.

^bAnnual. Based on *IPA-OG* and US producer price index.

Further regressors: κ^f , μ^f , $\iota(\text{med. } L^{tot})$, $\iota(\text{big } L^{tot})$, $\iota(\text{med. cap.})$, $\iota(\text{big cap.})$, sector demand, FDI flow, cumulated FDI, and a *constant*.

firms into exporters.

Findings for both tariffs and the real exchange rate show that reduced barriers to imports bring about more exits. Firms choose next period's state of operation with regard to market prospects (exit in the data means exit in the following year). So, tariffs here are next year's tariffs. The lower the tariff, the more likely it is that a firm goes out of business (columns 3 and 6). The estimate of -1.73 in column 6 means that a reduction of tariffs by 10 percentage points (.1) raises the exit probability by 1.2 ($= e^{-1.73}$) percent relative to a non-exporter's likelihood of remaining a non-exporter. Similarly, lower tariffs make it more likely that a firm suspends production (column 5), possibly to wait for a return to higher tariff protection.

A low (appreciated) real exchange rate has a similarly strong effect on exit (columns 3 and 6) but no significant effect on the suspension decision

Table 11: MULTINOMIAL LOGIT ESTIMATES OF TRANSITION PROBABILITIES

ln <i>TFP-OLS</i>	$\sigma_{i,t}$ $\sigma_{i,t+1}$	Exporter			Non-Exporter		
		Non-Exp.	Susp.	Exit	Exp.	Susp.	Exit
		(1)	(2)	(3)	(4)	(5)	(6)
Nominal tariff ^a		2.072 (.304)	-.393 (1.135)	-2.676 (.985)	-.625 (.153)	-1.023 (.573)	-1.653 (.503)
Market penetration		.218 (.658)	-1.586 (1.946)	-.723 (1.226)	3.657 (.53)	-.992 (1.508)	2.466 (.986)
Real exch. rate (USD) ^b		-.761 (.272)	.552 (.811)	-2.759 (.688)	-1.558 (.132)	-.702 (.471)	-2.628 (.392)
ln <i>TFP-OLS</i>		-.123 (.052)	-.509 (.154)	.007 (.112)	.346 (.028)	-.357 (.092)	-.142 (.068)
Obs.				11,092		22,814	
Pseudo R^2				.046		.086	
$\hat{\chi}^2$				398.8		1470.5	
$Pr(\chi_{42}^2 > \hat{\chi}^2)$				.0000		.0000	

^aNext year's tariff.

^bAnnual. Based on *IPA-OG* and US producer price index.

Further regressors: Age, κ^f , μ^f , $\iota(\text{med. } L^{tot})$, $\iota(\text{big } L^{tot})$, $\iota(\text{med. cap.})$, $\iota(\text{big cap.})$, sector demand, FDI flow, cumulated FDI, and a *constant* (not reported).

(columns 2 and 5). Since firms are likely not able to predict the real exchange rate, current levels are used in the regression. The lower the real exchange rate, the harder it is to compete abroad, and more Brazilian exporters stop exporting (column 1). Surprisingly, a low real exchange rate induces non-exporting firms to start exporting (column 4). The result could possibly imply that exporters benefit from observing the influx of foreign goods to identify internationally competitive product characteristics.

In the previous MNL regressions, the government's choice of tariff levels, the real exchange rate and foreign competitors' market penetration are taken as exogenous to Brazilian firms' transition choices. However, the Brazilian government aimed to induce a *Competitive Push*. Similarly, foreign competitors care about the prevailing efficiency level in Brazil. Since productivity and not turnover was targeted, the inclusion of log *TFP* as a covariate should mitigate endogeneity concerns. To check the estimates, both changes and levels of potentially endogenous variables can be included in the MNL regressions. Table 10 (columns 4 through 6) shows the results for non-exporters. While the coefficient on market penetration changes to a certain degree, the estimate of the nominal tariff coefficient is stable across specifications.

In the absence of trade liberalization, industry turnover would have exhibited significantly less exits. A difference-in-difference analysis shows that exiting firms have 8.2 percent lower productivity than survivors on average. So, exits may help raise average productivity. However, the shutdown probability ranges between two and five percent only. The bearing of exits on aggregate productivity remains to be evaluated. A counterfactual simulation follows in section 5.

4.4 Possible additional effects

Entry is another aspect of turnover. Fiercer foreign competition can deter entry—a *Competitive Elimination* of business projects before they are realized. However, the present analysis excludes entry for two reasons. For one, entry was not always recorded systematically in *PIA*. Second, the counterfactual is hard to answer in general: How many more business proposals would have been pulled out from the drawers had trade not been reformed? It is likely that only the most productive projects will be realized after trade reform. Then the net effect on efficiency is ambiguous. Less but more productive entrants can move aggregate productivity either way.

At least from a theoretical perspective, there are two additional channels through which trade may affect productivity. In the aggregate of sectors, a fourth channel can be *Competitive Reallocation*. Less competitive firms lose market share, while more competitive firms grow in relative size. Models with Cournot or monopolistic competition predict this. In well-functioning factor markets, a reallocation of capital and labor to the more efficient firms should take place. The effect raises sector-wide productivity because averages are size-weighted. It is difficult, however, to relate size change directly to trade liberalization. In fact, it is likely to be an indirect effect in several ways.

First, trade encourages firms to raise individual productivity through a *Competitive Push* and a *Foreign Input Push*. Firms that are faster at adopting higher productivity grow in relative size. Therefore, size change gives the *Competitive Push* (1) and the *Foreign Input Push* (2) an extra boost. Similarly, after suspension or exit has occurred due to *Competitive Elimination* (3), the surviving firms grow in size and the fittest grow relatively faster. In this way, size change also reinforces channel 3 effects. Finally, increased foreign competition squeezes the market share of domestic Brazilian firms. Again, the less productive ones are squeezed more strongly which boosts effects from channels 1 and 2 further. On all of these accounts, size change should not necessarily be considered its own channel but rather an augment to previous channels. Olley and Pakes (1996) and Pavcnik (2002) show for US telecom suppliers and

Chilean manufacturers that more efficient plants grow faster, whereas Bernard, Jensen and Schott (2003a) and Muendler, Servén and Sepúlveda (2001) cannot confirm this for US manufacturing plants and Brazilian manufacturing firms.

However, size change does seem to be a channel of its own with regard to economies of scale. If economies of scale exist, firms that face import competition may suffer from lower scales of production after being squeezed, while exit of their domestic competitors helps them realize previously unexploited economies of scale. So, there are conflicting forces at work and it is not clear which would prevail. Studies that investigate scale effects from trade are, in general, not able to confirm an effect empirically (Tybout and Westbrook 1995, Roberts and Tybout, eds 1996). Unfortunately, productivity and economies of scale are not identified simultaneously when price is endogenous (Klette and Griliches 1996). So, this channel cannot be evaluated in the present context.

In the industry aggregate, a fifth channel of trade-related productivity effects is *Induced Specialization*. Due to Ricardian or Heckscher-Ohlin type forces of trade, a country's industry may specialize in sectors where the innovative potential is largely exhausted. Similarly, the erosion of rents for domestic producers may stifle product innovation. This can lower average productivity change and partly offset present channels. Theoretical contributions in favor of the hypothesis include Young (1991) and Xie (1999). This fifth channel cannot be evaluated in the current context with incomplete sector data. Using cross-country data, Weinhold and Rauch (1999) find empirical evidence against the hypothesis.

Finally, while firm heterogeneity as analyzed here dispenses with some assumptions behind classic trade theory, another important assertion deserves further scrutiny: The induced reallocation of workers and capital goods between firms and across sectors need not work perfectly. Possible costs have to be set against the gains from prior channels. Wacziarg and Wallack (*forthcoming*) uses cross-country data for 25 periods of trade liberalization and argues that trade liberalization has far smaller effects on labor reallocation across sectors than is often presumed. However, preliminary analysis for Brazil shows substantial layoffs and calls for further research.

5 Counterfactual simulations

To assess the relative importance of the three channels, one can switch them off individually and simulate log TFP in their absence. The first row in table 12 shows how productivity evolves in the sample for both the log $TFP-EOP$ and the log $TFP-OLS$ measures. Trade reform took effect in 1990, whereas previous

Table 12: COUNTERFACTUAL SIMULATIONS

Counterfactual		log <i>TFP</i>				
		1986	1990	1992	1995	1998
		<i>EOP</i>				
<i>De facto</i>		1	.9813	.9958	1.0001	1.0281
Ch. 1 off	Tariffs unchanged ^a	1	.9774	.9857	.9981	1.0291
Ch. 2 off	κ^f and μ^f lower ^b	1	.9776	.9955	1.0000	1.0271
Ch. 3 off	Tariffs unchanged ^c	1	.9813	.9957	1.0001	1.0279
		<i>OLS</i>				
<i>De facto</i>		1	.9721	.9835	.9845	1.0130
Ch. 1 off	Tariffs unchanged ^a	1	.9673	.9713	.9818	1.0141
Ch. 2 off	κ^f and μ^f lower ^b	1	.9656	.9822	.9838	1.0115
Ch. 3 off	Tariffs unchanged ^c	1	.9721	.9834	.9843	1.0126

^aTariffs are taken to affect *TFP* change according to the estimate in table 7, column 2.

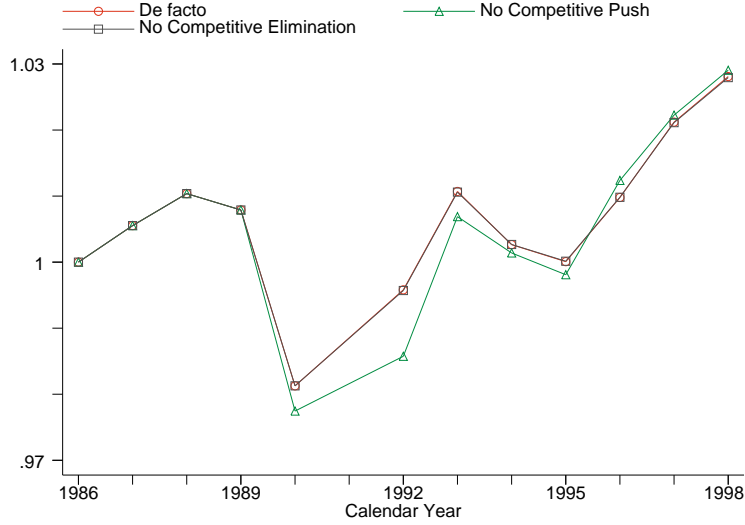
^bBased on separate regression estimates, a 10 percentage point lower tariff is taken to result in a 2.62 percentage point higher demand for foreign inputs relative to domestic inputs. This is a very favorable assumption.

^cTariffs assumed to affect exit according to estimates in table 9, columns 3 and 6. In the counterfactual sample, an according share of exiting firms is randomly kept (with productivity at the level of their *de facto* exit).

tariff reductions did most likely not matter for productivity change because non-tariff barriers remained binding. To base the following simulations on a parsimonious set of assumptions, non-tariff barriers and indirect productivity effects from import demand are discarded. Only the direct effect of tariffs on productivity is considered.

To assess the *Competitive Push* (1), I reduce each individual firm's observed *TFP* by $\hat{\Delta} \ln TFP_{i,t} = -.611(\tau_t - \tau_{t-1})$ year over year between 1990 and 1998 (but not cumulatively). The coefficient estimate $-.611$ for tariff levels is taken from table 3, column 2. Now, τ_t denotes nominal tariffs for products in that firm's sector. By 1992, *TFP-EOP* would have been one percent lower had there not been an increase in foreign competition. Since tariffs were raised again after 1995, however, about .1 percent less *TFP-EOP* is observed in 1998 than would have been feasible had tariffs remained at their low.

For the *Foreign Input Push* (2), one needs to infer what share of foreign inputs after trade reform is due to lower tariffs. Firms did buy foreign equipment before trade liberalization. Lower tariffs will make the equipment cheaper, however, and boost demand. Simple regressions for the machinery and equip-



Data: Simulated and *de facto* productivity in PIA.

Figure 4: **Log TFP** under three scenarios

ment sector show that market penetration increases by 2.65 percent points when tariffs are lowered by 10 percentage points (the point estimate in a regression of penetration on tariffs is $-.265$ for equipment). This response is magnitudes stronger than the average across all sectors (of only 0.02 percentage points, coefficient $-.0016$). The machinery estimate is likely upward biased because tariffs also catch the effect of changing non-tariff barriers. The estimate is still used both for equipment and foreign intermediates to provide a favorable upper bound in the simulation. Even then, the simulated impact of foreign factors on productivity is small.

The counterfactual share of foreign equipment (between 1990 and 1995) is calculated as $\hat{\kappa}_{i,t}^f = \kappa_{i,t}^f + .265 \cdot (\tau_t - \tau_{1988})$, where τ_t denotes nominal tariffs on investment goods in year t (measured on a scale from 0 to 1). This is a further favorable assumption for channel 2 since shares of foreign equipment in installed capital would not respond as fast as acquisitions. I apply a similar calculation to foreign intermediates (1996 through 1998). Here the 2.65 percent-point response of market penetration to a 10 percent tariff reduction is overly favorable. Even under such favorable assumptions, the simulation results in table 12 vindicate that this channel is not important. Except for a detectable immediate effect in 1990, productivity would have evolved largely in the same way had less foreign inputs been used.

Similar simulations for foreign intermediate goods would yield a more noticeable impact for the period 1996-98. However, this simulation is plagued

with substantial measurement error. In fact, in only one of 27 sectors the coefficient estimate on foreign intermediate goods is significant under EOP estimation. At a significance level of .95, 20 tests likely yield significance in one case by mere chance. The simulated value for 1998 should therefore be taken very cautiously.

For *Competitive Elimination* (3), I simulate exit among exporters and non-exporters. Given the standardization chosen in the MNL model of section 4.3, the expected share of exits in year t is $\mathbb{E}[n_{exit,t+1}/N_{active,t}|\tau_t] = \exp[\hat{\beta}_\tau(\tau_t - \tau_{1988})] \cdot P(\tau_{1988})$ where $\hat{\beta}_\tau$ is the coefficient estimate for tariffs (table 9, columns 3 and 6). Expected exit would be $\hat{\mathbb{E}}[\hat{n}_{exit,t+1}/N_{active,t}|\tau_{1988}] \equiv P(\tau_{1988})$ at 1988 tariffs. So, one can consider $1 - \exp[-\hat{\beta}_\tau(\tau_t - \tau_{1990})]$ an estimate for the relative share of exits $(n_{exit,t+1} - \hat{n}_{exit,t+1})/n_{exit,t+1}$ that is attributable to tariff reductions. To assess the counterfactual of frozen tariffs at the 1988 level, I had a share $1 - \exp[-\hat{\beta}_\tau(\tau_t - \tau_{1988})]$ randomly drawn from the observed exiting firms and put back into the sample, duplicating their year t observation for $t + 1$ and beyond.

The reported EOP (OLS) simulation randomly added 281 (350) observations of otherwise exiting firms to the total sample of 42,024 (42,093) valid observations. There is no immediate productivity effect from exits in 1990. This may mean that trade reform induced both high and low productivity firms to exit initially. Anecdotal evidence for the equipment sector, for instance, confirms this. Relatively advanced firms chose to exit in the early nineties since their products could often not compete with foreign goods, while domestic firms with products in low-quality and low-productivity niches were favored. By 1998, there is a small but detectable effect. Since this channel unfolds its impact over time and no favorable assumptions go into the simulations (as opposed to channel 2), the simulated outcomes should be interpreted somewhat more favorably. Had exiting firms stayed, productivity could have been up to .6 percent lower—about a tenth of the *de facto* productivity change between 1990 and 1998.

Figure 4 depicts simulation results for the *Competitive Push* and *Competitive Elimination*. The *Competitive Push* (1) has a considerable and immediate impact on productivity. Competitive elimination (3) affects too few firms to have an immediate effect but unfolds some impact over time. Qualitative evidence confirms this pattern.

Amann (1999) studies the Brazilian non-serial capital goods sector and argues that managers did not find foreign inputs with embodied technology a major source for innovation (p. 342). In other words, they did not expect much of a *Foreign Input Push* (2). Amann (1999, p. 351) also states that managers restructured processes after 1989 but engaged in little efforts of their

own to innovate products. This supports the importance of the *Competitive Push* (1). However some managers chose to obtain foreign designs to improve their products (Amann 1999, p. 342). That is a possibly important channel of knowledge flows unrelated to the flow of traded goods.

On all those accounts, only the *Competitive Push* seems to drive a salient part of productivity change, while neither the *Foreign Input Push* nor *Competitive Elimination* can exert a noticeable impact over the horizon of a decade.

6 Conclusion

Brazil's trade liberalization in the early 1990s presents a focused policy experiment to trace effects of trade on productivity change. The federal government slashed inward trade barriers to less than a quarter of their initial levels within three years but left outward trade barriers largely untouched. A sample of 9,500 medium-sized to large Brazilian manufacturers is followed over the period from 1986 until 1998. For the first time, three channels of trade-induced productivity change can be distinguished in this data set: (1) Foreign import competition in product markets exerts a *Competitive Push* on individual firms. Theory predicts that managers may choose to innovate processes and remove slack under fiercer competition. (2) Easier access to foreign equipment and intermediates may allow for a *Foreign Input Push* at the firm level. (3) Competition in the product market may also induce more exits and bring about a *Competitive Elimination* of inefficient firms.

Productivity measures from three alternative methods are calculated (an index with assumed capital-goods intensity of a third, an index from OLS production function estimates, and an index from an extended Olley and Pakes 1996 algorithm). The measures yield similar results.

Trade liberalization induces competitive pressure. It unleashes a *Competitive Push* on firms to raise their efficiency (channel 1). This proves to be a noticeable source of productivity change. Controlling for the endogeneity of foreign market penetration and tariffs through instrumental variables (components of sector-specific real exchange rates), small changes in the tariff act are shown to induce considerable efficiency improvements among surviving firms. However, the *Foreign Input Push* (channel 2) is found to be relatively unimportant. The efficiency difference between foreign and domestic inputs has only a minor bearing on productivity. Foreign technology adoption likely takes time due to learning effects, factor complementarities and necessary production rearrangements. When trade barriers fall, the *Competitive Elimination* of the least efficient firms (channel 3) strikes more fiercely. Estimates of turnover probabilities in multinomial logit regressions confirm that both the likelihood

of survival drops markedly when trade barriers fall and that low-efficiency firms go out of business more frequently. Counterfactual simulations indicate, however, that *Competitive Elimination* only slowly unfolds a modest impact on aggregate productivity. It stems from just a small share of firms.

Simulations underscore the force of the *Competitive Push*. This channel is a remarkable source of productivity change among Brazilian manufacturers between 1990 and 1998.

Beyond these three direct channels, several further and mostly indirect effects of trade on the production sector deserve attention. Productivity changes among survivors and exits of the least efficient firms induce *competitive reallocations*. More efficient firms typically gain market share so that size change is as an augment to the three direct channels analyzed here. Trade may induce less developed economies to *specialize* in low-growth sectors. Similarly, trade may stifle innovation as rents erode with foreign competition. Finally, the effectiveness and costliness of the induced factor reallocation deserves closer scrutiny. In the latter cases, potential costs need to be set against the gains to the production sector. Since the gains are found to be small despite Brazil's substantial trade reform and despite the neglect of costs, the largest benefits from trade may indeed be those to consumers, as classic trade theory posits, and not those from induced changes to the production technology.

Appendix

A Firm-level Data Construction

The Brazilian statistical bureau (*IBGE*) conducts an annual survey of mining and manufacturing firms, called *Pesquisa Industrial Anual (PIA)*. It comprises a sample of formally established, medium-sized to large Brazilian firms for the years 1986 to 1990, 1992 to 1995, and 1996 to the present. Mining is disregarded in this paper.

Muendler (2003) documents the construction of an unbalanced panel data set from *PIA* in detail—including the establishment of longitudinal relations between firms (such as entry, creation, exit, and mergers or acquisitions), consistency adjustments for economic variables due to questionnaire changes, price deflation of the economic variables, and the derivation of consistent capital stock series. This appendix merely summarizes the resulting data characteristics.

A firm qualifies for *PIA* if at least half of its revenues stem from manufacturing activity and if it is formally registered with the Brazilian tax authorities. In 1986, the initial *PIA* sample was built on three layers: (1) A non-random sample of the largest Brazilian manufacturers with output corresponding to at least 200 million Reais in 1995 (around 200 million US dollars in 1995). There were roughly 800 of them. (2) A random sample among medium-sized firms whose annual output in 1985 exceeded a value corresponding to R\$ 100,000 in 1995 (around USD 100,000 in 1995). More than 6,900 firms made it into *PIA* this way. (3) A non-random selection of newly founded firms. *PIA* only included new firms that surpassed an annual average employment level of at least 100 persons. The inclusion process ended in 1993, however. Until then, around 1,800 firms were identified in this manner.

A firm that entered *PIA* through one of the selection criteria for medium-sized to large manufacturers in 1986 remains in the sample until it is legally extinct. Moreover, if a firm in *PIA* reports the creation of a new firm as a subsidiary, affiliate, related firm or spin-off, this new firm enters *PIA* too. No sample was taken in 1991 due to a federal austerity program. The sampling method changed in 1996, and no capital stock figures are reported since. Therefore, the data set of this paper only embraces firms after 1995 that were present in *PIA* earlier or that were longitudinally related to an earlier firm. Their capital stock is inferred with a perpetual inventory method. Following the change in sampling, there is a drop in the sample in 1996. Tests at various stages of production estimation prove it exogenous.

Economic variables in *PIA* include sales figures and changes in final goods stocks, costs of inputs, salaries, employment of blue- and white-collar workers, and several variables related to investment and the capital stock. Most interestingly, firms in *PIA* report their acquisitions of foreign equipment until 1995 and their purchases of foreign intermediate goods since 1996.

Domestic data are deflated with three different price indices to check for sensitivity. The sector-specific wholesale price index *IPA-OG* underlies all results in this

paper. Another sector-specific wholesale price index, *IPA-DI* (excluding imports), and the economy-wide price index *IGP-DI* (a combined wholesale and consumer price index) do not yield substantially different results. There is no producer price index for Brazil. Output and domestic inputs are deflated with sector-specific price indices (constructed on the basis of Brazilian wholesale price indices and input-output matrices). Capital stock figures and investments are deflated with economy-wide price indices (constructed on the basis of Brazilian wholesale price indices and economy-wide capital formation vectors).

Foreign equipment acquisitions and foreign intermediate inputs are deflated in two steps. First, sector-specific series of import-weighted foreign producer prices, adjusted for nominal exchange rate fluctuations relative to the US-Dollar, are applied. Then, (investment-weighted) nominal tariffs on foreign machinery and (sector-specific input-weighted) nominal tariffs on intermediates are removed from equipment acquisitions and intermediate inputs. This procedure resolves an otherwise possible tariff-induced correlation between foreign input values and the productivity index in the error term of the production function.

The overall capital stock is inferred under a perpetual inventory method that controls for changes to accounting law in 1991. Both investments and book values of capital goods are reported in *PIA* until 1995. Investments are assumed to become productive parts of the capital stock within the year of their reporting. They are used to infer typical depreciation rates through regression analysis. Foreign equipment levels are inferred from foreign equipment acquisitions and overall retirements. The structures part in total capital includes rented capital goods. These stocks of rented capital goods are inferred from reported rental rates, which are taken to equal the (time-varying) user cost of capital. Consistency adjustments are made under the perpetual inventory method when stock changes are observed that differ from net investments (different deflators can cause this). Usually, simple averages are used. Since sector-wide depreciation rates are applied, the resulting capital stock series for 1986-1998 are smoother across firms and over time than the raw series.

Sector classifications in *PIA* would allow for the estimation of production functions at a level that corresponds to three *ISIC rev. 3* digits (*nível 100*). However, large firms in *PIA* are likely to offer product ranges beyond narrowly defined sector limits. Data at more aggregate levels also provide more variation in the cross section because variables related to the market environment become available for two or more subsectors within several sectors. Those variables provide identification. Moreover, switching from the three to the two-digit level increases the number of observations per estimation considerably. So, estimation is carried out at two *ISIC* digits (*nível 50*).

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