A Model of Trade Liberalization and Technology Adoption with Heterogeneous Firms

Andrey Stoyanov*

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Abstract

This paper demonstrates that the reason for a higher capital-labor ratio, observed for exporting firms, is a higher capital intensity of their production technology. Exporters are more productive, more likely to survive and, hence, more likely to repay loans. A higher repayment probability causes creditors to charge lower interest rates, which stimulates exporters to switch to cost-reducing capital-intensive technologies. A reduction in international trade costs stimulates exporting firms to switch to more efficient capital-intensive technologies, while non-exporters stick to less capital-intensive ones. This within-industry change in the composition of technologies reinforces the productivity advantage of exporters and contributes further to industry-wide productivity improvement. The results of model simulations highlight that 5 – 10% of total welfare and productivity gains of trade liberalization can result from the adoption of new technologies by existing firms in the industry, thus amplifying the effect of resource reallocation arising from firms’ entry and exit.

*Economics, Faculty of Liberal Arts and Professional Studies, York University, 2009-4700 Keele Str., Toronto, ON, Canada; tel. +1 416 736 2100 ext 22833; fax +1 416 736 5188; andreyst@yorku.ca.

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1 Introduction

Recent empirical research using micro-level trade data has established substantial differences between exporting and non-exporting firms with respect to many performance characteristics. In their seminal work, Bernard and Jensen (1999) document that exporters operate at a larger scale, are more productive, pay higher wages, and use more capital per worker. In theoretical literature,
on the other hand, recent models of firm heterogeneity have been successful at explaining most of these differences between exporters and non-exporters. In particular, these models address the observed differences in productivity level and size (Melitz, 2003, Bernard et al, 2003), skill intensity and wage premium (Yeaple, 2005), and innovation activities (Atkeson and Burstein, 2007), as well as the importance of these differences for the effect of trade liberalization on aggregate productivity. However, the causes and implications of within-industry heterogeneity in factors’ proportions have not received enough attention in the theoretical literature.

This paper proposes a model that incorporates heterogeneity in capital intensities across firms to analyze the implications of this heterogeneity for trade policy outcomes and aggregate economic variables. The theoretical model builds on Melitz (2003) general equilibrium model with heterogeneous firms and product differentiation, and introduces two additional features, backed up by empirical evidence. First, we introduce into the model the well known empirical regularity that large and more productive firms pay lower interest rates on long-term loans than small firms. As such, this paper assumes that capital price is firm-specific and depends on repayment probability. Since more productive firms are less likely to receive a “death shock” and to exit the market than less productive firms, the former are more likely to repay loans used to finance capital purchases. Therefore, the likelihood of loan repayment is increasing with productivity and creditors will include a risk premium in capital price for low productivity firms.

Second, to replicate within-industry heterogeneity in capital intensities observed in the micro data of many countries, the model is further extended by allowing firms to choose their production technology endogenously from a pool of technologies with different capital intensities as measured by the output elasticity in a Cobb-Douglas production function. Upon entry, every firm uses the basic and the least capital-intensive technology, but once its productivity is revealed, the capital structure can be adjusted. In following periods, firms can choose from the menu of available technologies the one that maximizes the expected stream of profits, given the increasing adjustment costs of using more capital-intensive processes. These adjustment costs of adopting a more capital-intensive technology result from the necessity to rearrange the firm’s capital stock by simultaneous sales of old capital, which requires more workers to produce a unit of output, and purchase of new capital. Apart from direct capital costs, additional adjustment costs such as labor retraining, installing new and dismantling old equipment, etc., have to be covered. Additionally, during capital replacement, the old capital may lose part of its value.

This way of modelling technology adoption is novel in the literature that links trade and technology. In previous studies, new technology is typically associated with either the development of a new product (Grossman and Helpman, 1989, Coe and Helpman, 1995) or the increase in firm-
level TFP (Eaton and Kortum, 2001, Luttmer, 2007). In both cases, production technologies are identical across firms, except for TFP differences. In this paper, firms also differ in the way they organize production process and employ a mix of input factors. Here, we abstract from endogenous investments in TFP improvement or new product development in order to focus sharply on the effect of production process heterogeneity on aggregate productivity and trade.

Faced with different capital prices and increasing technology adjustment costs, firms have incentives to use different technologies: only the most productive firms will find it worthwhile to install a more capital-intensive technology, which gives them an additional cost advantage over other firms. Therefore, as long as exporting firms pay a lower capital price, they will endogenously choose technologies that use capital (cheaper factor) more intensively, thereby further reducing their costs of production.

The two key features of the model, namely firm-specific capital price and heterogeneity in capital-intensities of production technologies, have been documented in the recent empirical literature. Using French manufacturing firm-level data, Stoyanov (2011) analyzed the sources of within-industry differences in capital intensity and found two contributing factors. First, exporters pay a lower interest rate on long and short-term debt, presumably because of size and productivity advantages, and it stimulates them to substitute labour with relatively cheaper capital. Second, exporters were found to use more capital-intensive production technology in which there is a higher share of capital in the final output. With Cobb-Douglas production function, the capital share in the final output is about 25% higher for exporters when differences in capital and labour prices are controlled for. The capital intensity of future exporters starts increasing two years prior to entering foreign markets, and the transition process last four years, which suggests that exporting and re-organizing the production process are complementary decisions. Also, the average scale economies of exporters are not statistically different from those of other firms, so the difference in production technologies is not about differences in the economy of scale.

Furthermore, the higher capital intensity of exporters’ production technology is associated with higher total factor productivity. Results indicate that up to 30% of the productivity gap between exporters and non-exporters can be attributed to different organizational forms of the production process (Stoyanov, 2011). In the next section we incorporate factor price and production technology heterogeneity into a Melitz-type model of trade with heterogeneous firms and show that this combination is related to firm-level productivity. Therefore, the firm can increase or decrease its productivity by changing the organizational form of its production technology in the presence of factor price heterogeneity.

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2 Roll (1981) and Titman and Wessels (1988) argue that small firms are riskier and pay more for debt and equity issue. Easley and O’hara (2004) assert that small firms have to provide higher return on investments since they can reveal less information to the public.
We then calibrate the model developed in this paper to illustrate its implications for the trade policy analysis. We show that declining trade costs induce exporters to adopt more capital-intensive production technologies, which amplifies reallocation of resources to high productivity firms and leads to additional welfare and aggregate productivity gains. In equilibrium, a decline in trade costs has two effects. First, as in Melitz (2003), free trade causes within-industry reallocation of resources, forcing the least productive firms to exit and the more productive firms to enter export markets. Thus, trade costs reduction increases aggregate productivity by changing the composition of firms within the industry but does not affect firm-level productivity. The second effect of tariff reduction, not identified in previous literature, is that exporters switch to more productive and more capital-intensive technologies because they can spread the technology adoption costs over larger quantities of output. In equilibrium, the reduction in production costs by firms that install more advanced capital-intensive technologies results in reallocation of production shares toward exporters, which amplifies the initial reallocation effects and leads to a further increase in aggregate industry productivity. By disregarding the second effect, previous works have shut down a potentially important source of trade liberalization benefits and attributed within-industry technological changes to changes in TFP in empirical models. The results of our simulation exercises indicate that from 5% to 10% of the total effect of trade liberalization on aggregate productivity comes from the change in composition of technologies across firms rather than through the composition of firms within the industry.

Previous empirical literature has emphasized that not only do more productive firms self-select into export markets: exporting firms also experience a productivity increase after entering foreign markets through “learning-by-exporting”. This paper provides a new mechanism that relates export status with productivity growth. As long as risk premium decreases in productivity, more productive firms find it profitable to increase the capital-intensity of their production process. Moreover, for exporters, the productivity gain from investing in capital-intensive technologies raises the profitability of both domestic and foreign sales, thus raising their return to such investment relative to non-exporters. This result is consistent with recent findings by Baldwin and Gu (2003), Aw, Roberts, and Xu (2008), Bustos (2009), and Lileeva and Trefler (2009) that exporting is also correlated with R&D investments or new technology adoption.

The predictions of our model are related to theoretical papers by Atkeson and Burstein (2010), Aw, Roberts, and Xu (2010), and Melitz and Ottaviano (2008), which analyze the interdependence between a firm’s productivity, decision to export, and investment in R&D. They show that trade openness allows exporting firms to spread innovation costs over larger output levels and stimulates greater investment in innovation activities. Similar to this paper, these studies argue that trade in-

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3Empirical evidence on “learning-by-exporting” hypothesis can be found in De Loecker (2007), Alvarez and Lopez (2005), and Lileeva and Trefler (2009).
creases incentive for exporting firms to use more productive technology and, hence, raises aggregate productivity.\textsuperscript{4} However, in these models, a firm’s investments in innovation activities affect TFP directly, while in this paper we consider investments in a firm’s production organization process, which affects both the mix of input factors in the production and the firm’s productivity.\textsuperscript{5} As a result, the model explains why more productive exporting plants operate with more capital-intensive technologies, and reveals an additional channel for the welfare gains from trade liberalization arising from the change in the composition of technologies across firms.

The paper is organized as follows. Section 2 presents a theoretical model of endogenous technology choice with heterogeneous firms. Section 3 describes the model’s calibration strategy and the implications of trade barriers reduction for the aggregate economic variables. Section 4 concludes.

2 A Model of Technology Adoption and Trade

This section presents a general equilibrium model of firms’ decision to export and the choice of technology that may explain the firm-level differences in production technologies observed in the data. The model, based on Melitz (2003) model of monopolistic competition with heterogeneous firms, is extended to allow for endogenously chosen firm-specific production technology. Then the model will be used to analyze the impact of trade policy on incentives to use more capital-intensive technologies and aggregate productivity gains.

Consider two countries: home and foreign. Following the literature, the variables related to the domestic and exporting markets are denoted by upper indices $h$ and $x$, respectively. There are two sectors in the economy of each country: the homogeneous good sector producing good $z$ and the differentiated goods sector producing multiple varieties of good $X$.

2.1 Demand Side

A representative consumer in each country has Cobb-Douglas preferences over homogeneous and differentiated goods and CES preferences over the set of available varieties $N$ of a differentiated

\textsuperscript{4}Such complementarity between exporting and R&D investment intensity also appears in the models of Ekholm and Midelfart (2005), Costantini and Melitz (2007), Ederington and McCalman (2008), and others.

\textsuperscript{5}Similar to our model, Bustos (2009) analyzes the effect of exporting on investment in new technologies, characterized by higher productivity and skilled labor intensity. However, she assumes that more productive technologies are also more skilled labor intensive, while in our model factor intensity determines a firm’s productivity.
product:

$$U = z^{1-\eta} \left( \int_{j \in N} x_j^{\sigma-1} \, dj \right)^{\frac{\eta \sigma}{\sigma - 1}}$$

where $\eta$ is the share of consumer expenditure on differentiated products, $\sigma > 1$ is the elasticity of substitution between varieties, and $x_j$ is consumption of variety $t$.

Each country is endowed with non-depreciating labor stock $L$, supplied inelastically by consumers on the competitive labor market at price $\omega$. Maximizing this utility function subject to the standard budget constraint, we obtain aggregate industry-wide price index ($P$), and the demand and revenue functions faced by each firm in the economy ($x_j$ and $e_j$, respectively):

$$P = \left( \int_{j \in N} p_j^{1-\sigma} \, dj \right)^{\frac{1}{1-\sigma}}$$

$$x_j = \frac{I}{p_j} \left( \frac{p_j}{P} \right)^{1-\sigma} \quad (1)$$

$$e_j = I \left( \frac{p_j}{P} \right)^{1-\sigma} \quad (2)$$

where $I = \eta \omega L$ is the consumer’s total expenditure on differentiated goods.

2.2 Production Side

There is a continuum of potential firms that can freely enter the market for a homogeneous product. They all share the same linear production technology that uses only labor. Labor is supplied in a perfectly competitive market, which pins down the equilibrium wage rate. For simplicity, assume that both countries are equally productive in the homogeneous goods sector such that there are no cross-country wage differentials.

To enter the differentiated goods market, each firm has to make sunk entry costs $f_e$, measured in the units of final output. Upon entry into the market, the firm receives a productivity draw $A$ from the distribution function $G(A)$, which is constant over the life cycle of the firm, and decides whether to exit or stay in the industry. Firms produce final output using labor and capital according to the Cobb-Douglas production function with constant returns to scale and firm-specific productivity $A_j$:

$$Y_j = A_j K_j^\alpha L_j^{1-\alpha}.$$ The solution to the cost-minimization problem provides the following total cost function $C_j$:

$$C_j = \lambda_j (D_j + F)$$
\[ \lambda_j = \frac{1}{A_j} \left( \frac{r}{\alpha} \right)^\alpha \left( \frac{\omega}{1-\alpha} \right)^{1-\alpha} \]  \hspace{1cm} (3)

where \( D_j \) is the quantity demanded of variety \( j \), \( F \) is the fixed cost of production measured in terms of final output, and \( r \) and \( \omega \) are capital and labor prices, respectively. It follows that the marginal costs of production are constant and equal to \( \lambda_j \).

Each period, a firm receives an extreme cost shock with a probability \( \delta \) that forces it to leave the industry. Since more productive firms are less likely to be hit with a bad shock large enough to make the firm’s value non-positive, it is assumed that that the probability of a bad shock \( \delta(A) \) is a decreasing function of a firm’s productivity level: \( \frac{\partial \delta(A)}{\partial A} < 0 \).\(^6\)

### 2.3 Capital Market

Capital is produced from labor with a constant returns to scale technology: \( K = \gamma L^k \), where \( L^k \) is the amount of labor allocated to capital production. Consumers own capital and inelastically supply it to a risk-neutral perfectly competitive financial intermediary at market price \( r \). The intermediary in turn lends capital to firms. Perfect competitiveness implies that the price of capital observed by firms should include a risk premium, and since the chance of capital being repaid by a firm increases with its productivity, the risk premium is lower for more productive firms.\(^7\) It is also assumed that the productivity of each firm that sells on the market is perfectly observable to the financial intermediary since without any uncertainty the productivity parameter \( A \) can be revealed from the observable profit function and a firm’s size. Therefore, a firm \( j \) that operates in the market borrows capital at the competitive price \( r_j = r + \delta(A_j) \).\(^8\) However, the productivity of new firms is unobservable and the risk premium for the new firms simply equals the ex-ante probability of exit: \( r^e = r + \delta(E(A)) \).

\(^6\)In Section 3.1, we provide empirical evidence of the positive relationship between a firm’s survival probability and productivity.

\(^7\)Another reason that larger and more productive firms face lower interest rates that may result in a similar effect is that they have better access to the capital market and can reveal more company information to financial intermediates.

\(^8\)There is an extensive body of literature that documents a negative relationship between interest rate and firm size, e.g Bond (1983), Berkowitz and White (2004). For the French manufacturing industry Stoyanov (2011) reports the elasticity of interest rate, calculated as a ratio of debt payment over long term debt, with respect to output being equal to \(-0.11\) with \( t \)-statistics \(-119.5 \). Similarly, the elasticity of the interest rate with respect to the total factor productivity is \(-0.28\) with \( t \)-statistics \(-76.48 \).
2.4 The Choice of Technology

Each firm \( j \) operates with the Cobb-Douglas production function and firm-specific capital intensity \((\alpha + \rho T_j)\):

\[
Y_j = A_j K_j^{\alpha + \rho T_j} L_j^{1-\alpha - \rho T_j}
\]

where \( 0 < \alpha < 1 \) is the minimum level of capital intensity and \( T_j \in [0, 1] \) is a technology parameter normalized to a zero-one interval and chosen endogenously by each firm. Parameter \( \rho \in [0, 1 - \alpha) \) determines the minimum value of labor intensity \((1 - \alpha - \rho) > 0 \). Let \( h(T) \) be a technology adjustment cost function measured in terms of a final output with \( h'(T) > 0 \) such that more capital-intensive technologies require more investments. The technology adoption costs are modelled as annuity payment with a discount factor \( \delta \), so \( \delta(A_j) h(T_j) \) is paid each period by firm \( j \) for using production technology \( T_j \). Then each firm chooses \( T \) to maximize the discounted stream of profits:

\[
T_j^* = \arg \max \left\{ \sum_{t=0}^{\infty} (1 - \delta) \pi_{tj} \right\} 
\]

\[
\pi_{tj} = \frac{e^{tj}(\lambda_j(T_j))}{\sigma} - \lambda_j [F + \delta(A_j) h(T_j)]
\]

\[
\lambda_j(T_j) = \frac{1}{A_j} \left( \frac{\lambda_j}{\alpha + \rho T_j} \right)^{\alpha + \rho T_j} \left( \frac{\omega}{1 - \alpha - \rho T_j} \right)^{1-\alpha - \rho T_j}
\]

The first-order condition for maximization problem (4) is given by:

\[
\rho \left[ \frac{(1 - \sigma)}{\sigma} e(\lambda(A_j)) - \lambda(A_j)(F + \delta(A_j) h(T_j)) \right] \ln \left( \frac{1 - \alpha - \rho T_j^* r_j}{\alpha + \rho T_j^* w} \right) = \delta(A_j) \lambda(A_j) \frac{\partial h(T_j^*)}{\partial T_j^*}
\]

Equation (7) shows that a firm chooses the capital intensity of its production technology, \( T \), such that the marginal costs of technology adoption on the right-hand side are equal to the marginal benefits on the left-hand side. A decrease in the marginal costs of production \( \lambda \), implied by a more capital-intensive technology, affects the marginal benefit of adoption through two channels. First, it increases total revenue (the first term in square brackets); second, it decreases the marginal costs of technology adoption (the second term).

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9 In line with the empirical evidence from Van Biesebroeck (2005) and Stoyanov (2011) that both exporters and non-exporters operate with the same economies of scale, it is assumed that all available technologies are constant return to scale.

10 In practice, adoption costs are not recoverable. If market conditions change in such a way that new entrants choose to lower capital intensity, the incumbent firms will continue using their current technologies, for which they have already paid adoption costs. However, we still model \( h(T) \) as annuity payments since our model is focused on the steady state equilibrium, and in the long run all incumbent firms will be replaced with new ones, which optimally will choose lower \( T \) and pay less in adoption costs.
Modelling technology adoption as the decision concerning the capital intensity of the production technology is different from most of the existing literature in which technology choice is usually directly linked to the productivity parameter $A$. For example, in Ekholm and Midelfart (2005), Ederington and McCalman (2008), and Bustos (2009) new technologies are assumed to be those with a higher productivity parameter $A$ and higher fixed costs of adoption, while in the dynamic models of Costantini and Melitz (2007), Atkeson and Burstein (2010), and Aw, Roberts, and Xu (2010) firms’ R&D investments today are linked to more favorable draws of productivity parameter $A$ in the future. Although in our model different technologies are also associated with different marginal costs $\lambda$, this relationship is implicit and is propagated through variability in factor prices across firms.

2.5 Entry, Exit, and Exporting Decisions

If a firm decides to export its product to another country, in addition to the fixed costs of production, it needs to pay fixed costs of exporting, $f_{ex}$, and variable costs of an iceberg form, so an amount $\tau > 1$ of a final product must be shipped in order to sell one unit of output abroad. The fixed costs of exporting are modelled as an amortized per-period payment $f_{j,x} = \delta(A_j) f_{ex}$.

Observing isoelastic demands for its product, each firm sets profit-maximizing prices in the domestic and foreign markets as a constant markup over its marginal costs:

$$
p_{j}^{h} = \frac{\sigma}{\sigma-1} \lambda_j
$$
$$
p_{j}^{x} = \frac{\sigma}{\sigma-1} \tau \lambda_j = \tau p_{j}^{h}
$$

From equation (2), the revenue earned by a firm on the foreign market is a fraction of its revenue from domestic sales: $\pi_{j}^{h} = \tau^{\sigma-1} \pi_{j}^{x}$. Similarly, from (5), the firm’s profit from domestic and foreign sales can be represented as

$$
\pi_{j}^{h} = \frac{\sigma}{\sigma-1} - \lambda_j \left[ F + \delta(A_j) h(T_j) \right]
$$
$$
\pi_{j}^{x} = \frac{\sigma}{\sigma-1} - \lambda_j \delta(A_j) \left( f_{ex} + \Delta h(T_j) \right)
$$

where $\Delta h(T_j) = h(T_j^x) - h(T_j)$ represents additional expenditures on technology adoption by exporters, and $\pi_{j}^{h}$ and $\pi_{j}^{x}$ depend implicitly on $T$ through (7).

Once the firm makes an entry investment, its productivity is revealed, and the decision should be made whether to stay in the market or not. If productivity is not high enough to cover the fixed costs, the firm will decide to withdraw immediately. Therefore, the firm makes an exit decision by maximizing the firm’s value, which is the higher of its closing value, assumed to be zero, and the
discounted stream of profits:

\[ v(A) = \max \left\{ 0, \sum_{t=0}^{\infty} (1 - \delta(A))^t \pi(A) \right\} = \max \left\{ 0, \frac{\pi(A)}{\delta(A)} \right\} \]

Since \( v(A) \) is an increasing function of productivity, denote the lowest (cutoff) value for \( A \) required for the firm to earn a non-negative profit in the domestic market by \( A^* = \inf \{ A : v(A) \geq 0 \} \). Similarly, the productivity level \( A_x^* = \inf \{ A : A \geq A^* \text{ and } \pi^x(A) > 0 \} \) identifies the cutoff value required for entering the foreign market.

Given that the \textit{ex-ante} probability distribution function of productivities is \( G(A) \) with a positive support on a \([0, \infty)\) interval, the fraction of exporting firms (the probability of becoming an exporter) is equal to \( p^x = \frac{1 - G(A_x^*)}{1 - G(A^*)} \). The number of exporting firms, \( M_x \), is thus a fraction \( p^x \) of all firms that operate in the home market, \( M \), and, given symmetry, the total number of varieties available in each country is

\[ M_v = M + M_x = (1 + p^x)M \]

### 2.6 Equilibrium Distribution of Productivities

The firm’s equilibrium entry and exit rules determine the evolution of the distribution function of observed productivities:

\[ \mu_{t+1}(A, A^*) = \frac{s(1 - \delta(A))}{\int_{A^*}^{\infty} (1 - \delta(A)) \mu_t(A, A^*) dA} \mu_t(A, A^*) + (1 - s)g(A) \]

where \( s = \frac{M}{M + M_e} \) is the share of incumbent firms in the market, \( M_e \) is the number of new entrants, and \( g(A) = G'(A) \) is the probability density function of productivities of the new entrants. The first term reflects the change in the distribution of productivities due to the fact that less productive firms are more likely to exit. The second term captures the contribution of new entrants to \( \mu_{t+1} \).

The resulting equilibrium steady state distribution function of observed productivities is given by:

\[ \mu(A, A^*) = \frac{(1 - s)g(A)}{1 - \frac{s}{g}(1 - \delta(A))} \tag{10} \]

where the constant \( C \) is determined from the equation

\[ C = \int_{A^*}^{\infty} (1 - \delta(A)) \mu(A, A^*) dA = \int_{A^*}^{\infty} \frac{(1 - s)(1 - \delta(A))g(A)}{1 - \frac{s}{g}(1 - \delta(A))} dA \]
2.7 Open Economy Equilibrium

The following time structure in the problem of a firm’s decision-making is assumed. It the first stage, the firm makes a sunk entry investment \( f_e \). In the second stage, its productivity \( A_j \) is revealed, which becomes a common knowledge and determines the interest rate for capital, \( r_j \). Observing the capital price, the firm chooses how much to invest into production technology and whether or not to export. Next, the firm decides how much to produce and what price to charge in each market, as well as how much of each factor of production to use, given the market wage rate and return on capital. Finally, the realization of the exit shock \( \delta(A) \) is revealed.

Denote by \( \tilde{\lambda} = \tilde{\lambda}(A^*) \) the average marginal costs of all firms that sell domestically, weighted by output shares, and \( \tilde{\lambda}_x = \tilde{\lambda}(A^*_x) \) the marginal costs averaged across all exporting firms:

\[
\tilde{\lambda}(A^*) = \left[ \int_{A^*}^{\infty} \lambda(A)^{1-\sigma} \mu(A, A^*) dA \right]^{\frac{1}{1-\sigma}} \\
\tilde{\lambda}_x(A^*) = \left[ \int_{A^*_x}^{\infty} \lambda(A)^{1-\sigma} \mu(A, A^*) dA \right]^{\frac{1}{1-\sigma}}
\]

Let \( \tilde{\lambda}_t \) denote the industry-average marginal costs in the open economy with variable trade costs \( \tau \):

\[
\tilde{\lambda}_t = \left[ \frac{1}{M^\tau} \left( M\tilde{\lambda}\sigma^{-1} + M_x(\tau\tilde{\lambda}_x)^{\sigma^{-1}} \right) \right]^{\frac{1}{\sigma-1}}
\]

Average revenue and profit from domestic and foreign sales can also be expressed through average cost function and the corresponding productivity cutoff value. From (2) and (8), \( \frac{\varepsilon_n}{\varepsilon_m} = \left( \frac{\lambda(A_n)}{\lambda(A_m)} \right)^{1-\sigma} \) for any pair of firms \( n \) and \( m \). Therefore, the average revenue from domestic sales can be expressed as

\[
\bar{\varepsilon}_h = e_h(\tilde{\lambda}) = \left( \frac{\tilde{\lambda}(A^*)}{\lambda(A^*)} \right)^{1-\sigma} e(\lambda(A^*))
\]

and from (9) the average profit from domestic sales is

\[
\bar{\pi}_h = \pi_h(\tilde{\lambda}) = \left( \frac{\tilde{\lambda}(A^*)}{\lambda(A^*)} \right)^{1-\sigma} \frac{e(\lambda(A^*))}{\sigma} - \tilde{\lambda}(A^*) \left[ F + \delta(A^*)h \left( \tilde{\lambda} \right) \right]
\]

Following Melitz (2003), the zero cutoff profit condition (ZCP) requires the profit of a firm with the marginal productivity \( A^* \) to be equal to zero, or, equivalently:
\[
\pi_h(\lambda) = k(A^*)\tilde{\lambda}(A^*) \left[ F + \tilde{\delta}(A^*) \frac{(1-G(A^*))M^e}{M} h\left(\tilde{T}^e\right) \right]
\]

\[
k(A^*) = \left[ \left( \frac{\lambda(A^*)}{\tilde{\lambda}(A^*)} \right)^\sigma - 1 \right]
\]

where \(\tilde{T}^e\) is the output-weighted technology choice by new entrants, \(\tilde{\delta}(A^*) = \int_{A^*}^\infty \delta(A) \left( \frac{q(\lambda)}{\tilde{q}(\lambda)} \right) \mu(A) dA\) is the weighted average exit rate given \(A^*\), and \(\frac{(1-G(A^*))M^e}{M}\) is the share of successful entrants. Therefore, \(\tilde{\delta}(A^*) \frac{(1-G(A^*))M^e}{M} h\left(\tilde{T}^e\right)\) is the average cost of technology adoption per firm. Furthermore, \(\tilde{T}^e\) is completely determined by the threshold productivity level \(A^*\) as can be observed from (7).

Additionally, using (9) and repeating the same analysis for export profits, the average profit from foreign sales can be expressed as a function of the export productivity threshold \(A^*_x\):

\[
\pi_x(\lambda_x) = \tilde{\lambda}(A^*_x) k(A^*_x) \tilde{\delta}(A^*_x) \left[ f_{ex} + \Delta h(T^*_x) \right]
\]

Combining (14) and (15), the aggregate ZCP condition in the open economy becomes:

\[
\bar{\pi} = \pi_h(\tilde{\lambda}) + p^x \pi_x(\tilde{\lambda}_x)
\]

Condition (16) defines the first equilibrium relationship between average profit and a cutoff productivity level \(A^*\). Note that in (16) the cutoff productivity level for exporting is an implicit function of \(A^*\). From (2), \(\frac{c_n}{c_m} = \left( \frac{p_n}{p_m} \right)^{1-\sigma}\) for any pair of firms \(n\) and \(m\). In particular, \(\frac{c_n(A^*)}{c_m(A^*_x)} = \left( \frac{\lambda(A^*)}{\tilde{\lambda}(A^*_x)} \right)^{1-\sigma}\). Furthermore, from the zero profit condition for a firm with a threshold value of productivity, the following equalities must hold: \(\frac{c_n(A^*)}{\sigma} = \lambda(A^*) \left[ F + \delta(A^*)h(T^*) \right]\) and \(\frac{c_m(A^*_x)}{\sigma} = \lambda(A^*_x) \delta(A^*_x) \left[ f_{ex} + \Delta h(T^*_x) \right]\). These conditions imply that the cutoff value for entering exports market can be expressed as a function of the domestic market cutoff value:

\[
\lambda(A^*_x) = \gamma^{1-\sigma} \lambda(A^*) \left( \frac{F + \delta(A^*)h(T^*)}{\delta(A^*_x) \left( f_{ex} + \Delta h(T^*_x) \right)} \right)^{\frac{1}{\sigma}}
\]

If the firm decides to enter the market, it should pay a sunk entry cost \(f_e\). The free entry condition requires that the firm value of a potential entrant should be equal to zero, \(v_e = \frac{1-G(A^*)}{\lambda[A|A \geq A^*]} \bar{\pi} - f_e = 0\), and it provides the second equilibrium relation between average profit and marginal productivity:

\[
\bar{\pi} = \frac{\delta [E(A|A \geq A^*)]}{1 - G(A^*)} f_e
\]

where \((1 - G(A^*))\) is the probability of successful entry and \(\delta [E(A|A \geq A^*)]\) is the ex-ante probability of a bad shock.
Conditions (16) and (18) determine the open economy equilibrium and are similar to condition (12) in Melitz (2003) but in the presence of capital in the production function, variable probability of survival, and endogenous technology choice by firms. In the same way, these conditions identify unique equilibrium values of $A^*$ and $\pi$. Note that the variance in technologies across firms does not affect the equilibrium conditions explicitly.

Once the industry average marginal costs are known, it is possible to derive all other long-run equilibrium aggregate economic variables for the open economy. Knowing the pricing rule (8), the equilibrium price index can be expressed in terms of $\tilde{\lambda}$:

$$ P = \frac{\sigma}{\sigma - 1} M \frac{1}{1-\sigma} \tilde{\lambda} = M \frac{1}{1-\sigma} \bar{p}(\tilde{\lambda}) $$

Similarly, consumption index, aggregate revenue, and profit can be expressed through the industry-average marginal costs:

$$ Q = M \frac{\sigma}{\sigma - 1} \tilde{q}(\tilde{\lambda}) $$

$$ E = M \bar{e}(\tilde{\lambda}) $$

$$ \Pi = M \left( \frac{e(\tilde{\lambda})}{\sigma} - \tilde{\lambda} \left[ F + \delta(A_j)h \left( \tilde{T} \right) \right] \right) = M \pi(\tilde{\lambda}) $$

Factor demand conditions (A1-A2) imply that total payment to labor and capital used in the production must be equal to total costs (the revenue net of the profit), while the market clearing condition for the final product requires equality of total revenue and total expenditure: $E = I = \omega L$. Together, these conditions imply that total payment to investment workers should equal aggregate profit: $\omega L^e + rK^e = M^e f_e = \Pi$. The equality of aggregate revenue and consumer income determines the total number of incumbent firms in the market, while the equality of aggregate profits and investment costs pins down the equilibrium number of new entrants:

$$ M = \frac{\omega L_e}{\pi} $$

$$ M^e = \frac{M \pi}{f_e} $$

(19)

Normalizing the wage rate to one, the equilibrium risk-free capital price follows from the no-arbitrage condition on factors market that labor income in the homogeneous good sector and in the production of capital should be the same:

$$ \omega = 1 = \gamma r $$

(20)

Conditions (16) and (18) characterize the open economy equilibrium, which determines equilibrium average profit, cutoff productivity level, and relative factor prices. Conditions (7), (10), (17), (19) and (20) complete the characterization of the stationary equilibrium.
2.8 The Effect of Trade Barriers Reduction

Now we can perform some comparative statics analysis of the model’s stationary equilibrium and look at the effect of a trade policy change on the open economy equilibrium outcome. Our prime interest is the effect of a reduction in trade barriers following from a decline in tariff or non-tariff barriers. The effect of a tariff reduction can be observed through comparative static analysis of (16) and (18) conditions with respect to \( \tau \).

Denote \( x \) and \( x' \) the value of a variable \( x \) before and after policy change, respectively. Inspection of conditions (16) and (18) reveals that the reduction in variable trade costs from \( \tau \) to \( \tau' < \tau \) will deliver a new ZCP curve that lies above the old one, keeping the FE curve constant. If trade barriers are reduced, domestic firms will face increased competition from the side of the most efficient foreign exporters and will lose some of their domestic market share to foreign firms. The least productive domestic firms with productivity levels close to \( A^* \) will not make enough revenue to cover fixed costs of production and will be forced to exit, so the threshold level \( A^* \) will increase. On the other hand, the most productive firms will enter the export market: from (17), a reduction in import tariff followed by the increase in \( A^* \) implies a decrease in the productivity threshold required to enter the export market: \( A^* > A^*' \).

From (16) and (18) it directly follows that the average profit and average revenue will increase in an economy with lower trade barriers, while the number of domestic firms will decrease.\(^{11}\) At the same time, the total number of product varieties available in each country will expand (\( M_o > M_a \)) and the increase in the number of exporters will outweigh the number of exiting firms. The decline in the output-weighted average costs \( \tilde{\lambda}' < \tilde{\lambda} \) can be interpreted as a reduction in aggregate costs (increase in aggregate productivity) when trade distortions are reduced, reflecting a country’s gain from within-industry resource reallocation as a result of openness to international trade.

We now look at the effect of trade on the adoption of more capital-intensive technologies. First, note that the FOC (7) and the fact that trade raises average revenue and lowers average costs implies that the industry-average technology adoption \( \tilde{T} \) necessarily increases in the economy with smaller variable costs of trade for any technology adjustment cost function \( h(T) \). The reason for this is that a firm’s market share reflects its ability to exploit the benefits of new technology adoption: increased revenue raises the returns to the new technology and results in an upward shift of the marginal benefit curve (LHS in equation 7) of technology adoption as a function of

\(^{11}\)Recall that from (2) \( \frac{e_n}{e_m} = \left( \frac{\lambda(A_n)}{\lambda(A_m)} \right)^{1-\sigma} \) for any pair of firms \( n \) and \( m \). Contrasting average revenue before and after tariff reduction, we obtain \( \frac{\pi}{\pi'} = \left( \frac{\lambda}{\lambda'} \right)^{1-\sigma} \). Since \( \frac{\partial \lambda(A^*)}{\partial A} = \int_{A}^{A'} \lambda(A)^{1-\sigma} \mu(A) dA - \lambda(A)^{1-\sigma} \mu(A^*) \) < 0, the result that \( A^* > A^* \) implies \( \lambda < \lambda' \) and \( \pi < \pi' \). Then, using (19), we obtain the required result: \( M > M' \).
Therefore, as long as openness to trade raises the average size of the firm, the average capital intensity will increase as well.

The average increase in capital intensity comprises two effects. The first, the composition effect, follows from the reallocation of market shares from the least productive firms to the most productive ones that have already installed more capital-intensive technologies. Therefore, exit of the least capital-intensive firms and the following change in the composition of firms in the market is one of the reasons that \( \tilde{T} \) increases in an open economy. The second effect is due to the change in the structure of technology adoption across survived firms. To better understand this structural effect, we need to analyze how trade affects a firm’s incentive to change its production technology.

Inspection of the FOC (7) reveals that trade affects the choice of \( T_j^* \) by firm \( j \) only through the effect on revenue. As previously discussed, if a firm’s revenue increases as a result of a policy change, an increase in the marginal benefit of technology adoption raises \( T_j^* \), unless \( T_j^* = 1 \) or the marginal benefit of technology adoption is non-positive. Therefore, using the insight of Melitz (2003), who showed that openness to trade increases the revenue of exporting firms and decreases that of non-exporting firms, the effect of trade on the structure of technology adoption can be summarized by the following proposition:

**Proposition 1** When import tariffs decrease, technology adoption by exporters in the economy with reduced tariffs will (weakly) increase, and adoption by non-exporters will (weakly) decrease.

The idea of Proposition 1 is illustrated in figure 1, where a firm’s productivity is mapped to its marginal costs and to the capital intensity of its production technology. Pre-trade and post-trade liberalization relationships are shown as solid and broken lines, respectively. The dotted line shows the relationship between productivity level and production costs in the benchmark model, where all firms have constant capital intensity equal to \( \alpha \). As figure 1 shows, a firm should reach a certain level of productivity \( A_0 \) when capital price becomes low enough for investment in technology adoption to be worthwhile, i.e. a firm with productivity \( A \leq A_0 \) will choose \( T^* = 0 \) and capital intensity \( \alpha \). Furthermore, all firms with productivity above \( A_1 \) will choose \( T^* = 1 \) and capital intensity \( (\alpha + \rho) \). Since technology adoption decision is crucially affected by the firm’s export status, there are three possible scenarios for the effect of trade, depending on whether the exporting threshold productivity is less than \( A_0 \), greater than \( A_1 \), or lies in between. Figure 1 illustrates this idea.

Figure 1(a) represents the case when technology adjustment costs are relatively high or exporting costs are low so that \( A^*_x < A^*_0 \). In this case, only the most productive firms would choose positive \( T^* \), while less productive exporters and none of the non-exporters would have incentives to change their technology after the tariff cut. In this case, the reduction in \( \tau \) would shift both \( A_0 \) and \( A_1 \)
toward $A^*_x$, and the distribution of capital intensities and marginal costs would change from the solid to the broken line. Only exporters in $[A'_0; A'_1]$ region would change their technologies and reduce marginal costs of production after the policy change, while non-exporters and exporters with productivity below $A'_0$ and above $A'_1$ would continue to use their original technologies. It is the firms with productivity levels in the interval $[A'_0; A'_1]$ that respond to the increase in the revenue with increased investments in capital-intensity. The ability to use a cheaper factor of production more intensively allows these firms to cut production costs and represents an additional source of increase in revenue and profits of exporters. Furthermore, a change in the distribution of marginal costs leads to a reduction of the industry-average marginal costs $\bar{\lambda}$ and contributes to an increased welfare per worker. Thus, the effect of trade on productivity through reallocation of market shares toward more productive firms, identified by Melitz (2003), is amplified by the firms’ decisions to invest in technology improvements.\footnote{This result is related to a large body of literature on trade and technology adoption with heterogeneous firms. As Melitz shows, reduction in trade barriers leads to an expansion in the profits of exporting firms and a contraction in the profits of non-exporting ones. Thus, trade cost reduction increases incentives to invest in new technologies by exporters and decreases that of non-exporters, thus amplifying the effect of resource reallocation from non-exporters to exporters. Similar results were obtained by Atkeson and Burstein (2010) and Aw, Roberts, and Xu (2010).}

Figure 1(b) represents the opposite case when technology adjustment costs are relatively low or trade costs are high so that $A^*_x > A'_1$. With all exporters already using the most capital-intensive production technology, according to Proposition 1, it would be only non-exporters who respond to change in the trade environment by (weakly) lowering capital intensity of their technologies. Since tariff reduction does lower revenues of non-exports, it makes capital-intensive technologies less valuable for domestic firms with productivity levels close to $A'_1$, and both $A'_0$ and $A'_1$ shift toward $A^*_x$. As a result, firms with productivity levels in the range $[A'_0; A'_1]$ would switch to less capital-intensive and less productive technologies, raising the industry-average marginal costs $\bar{\lambda}$ and decreasing the welfare per worker.

Finally, figure 1(c) represents an intermediate case in which the productivity threshold level for exporting lies in between $A'_0$ and $A'_1$. In this case, exporters with productivities in the interval $[A^*_x; A'_1]$ would install more productive and more capital-intensive technologies once trade distortions were reduced, while non-exporters with productivities in the range $[A'_0; A^*_x]$ would choose to have lower $T^*$. Since the revenue of a firm with productivity $A^*_x$ is higher under free trade, it would choose a higher $T$ in the open economy. Therefore, the two technology adoption curves must intersect to the left of $A^*_x$. Although the exact effect of technology adoption on aggregate productivity is indeterminant, we already know that the industry-average technology adoption $T$ necessarily increases in an open economy. In fact, even if the average productivity of survived firms decreased in the open economy, the effect of reallocation of market shares from less capital-intensive firms to more capital-intensive exporters would dominate.
3 Quantitative Analysis

This section describes the quantitative version of the model from Section 2. The quantitative analysis allows us to measure the relative strength of the technology adoption effect on aggregate productivity relative to the original effect of trade on within-industry reallocation of labor identified by Melitz (2003). It explores the quantitative implications of trade barriers on the aggregate economic variables in a series of counterfactual experiments in trade liberalization.

3.1 Parametrization

In this section we discuss the functional forms and parameter values used in the simulation exercise. To pin down values of parameters that have no obvious value, throughout this section we use various moment conditions observed in the French manufacturing sector for the period 1997 to 2005 and reported in Stoyanov (2011). The parameter values used in the simulation are reported in Table 1.

The endowment of labor in each country is normalized to \(L = 100\), and \(\sigma\) is set to be equal to 3 to reflect a 50% producer markup over marginal costs. The fixed costs of exporting were set to match the fact that 34% of French firms operate in foreign markets. This implies that, in the steady state, fixed export costs equal to approximately 16% of the export revenue for an average exporter. Since all statistics are invariant to proportional changes in fixed costs of entry, export and production, sunk entry costs and fixed costs of production were both normalized to one: \(f_e = 1\); \(F = 1\). Variable trade costs \(\tau\) was measured in two ways. First, \(\tau\) was proxied by the trade-weighted tariff for French imports, which was equal to \(\tau_0 = 1.08\) in 1997 and \(\tau_1 = 1.03\) in 2005. Second, \(\tau_0\) and \(\tau_1\) were set to deliver export intensity of manufacturing industries observed in 1997 and 2005, which have increased from 0.24 to 0.33. This gives the values of \(\tau_0 = 1.53\) and \(\tau_1 = 1.3\).

Following a general approach in the literature, we parameterize the distribution function of productivity draws by new entrants \(G(A)\) to be Pareto with the shape parameter \(\theta\) and the lower bound normalized to one. The shape parameter was set to match a 10% productivity advantage of the French exporters relative to non-exporters. This delivers the value of \(\theta = 3\), which is very close to the 3.4 obtained by Bernard, Eaton, Jensen, and Kortum (2003) for US firms. The probability of exit shock is parameterized with the logistic function of a firm’s productivity \(\delta(A) = (1 + \exp(d_0 + d_1 A))^{-1}\) where \(d_0\) and \(d_1\) are scalars estimated from the data.\(^{13}\) The risk-inclusive

\[^{13}\text{Parameters } d_0 \text{ and } d_1 \text{ were estimated from the logit model of the firm’s survival probability on productivity, measured by value added per worker, controlling for the firm’s age, legal status, geographical location and industry. Alternatively, productivity was measured with fitted residuals from estimates of the Cobb-Douglas production function and adjusted to account for different scales by matching the survival probability of the 25th and 75th percentiles of productivity in simulation and logit model prediction. Both methods yield very similar statistically significant estimates of } d_0 = 2.9 \text{ and } d_1 = 0.08.\]
capital price \((r + \delta(A))\), measured in units of labor, was obtained from the estimated survival probability by scaling it proportionally in such a way that even the marginal firm would have an incentive to increase capital intensity.

To solve the model, we also parameterize the technology adoption cost function \(h(T)\) in such a way that it could reproduce the technology adoption patterns observed in the data. In particular, since marginal cost is a decreasing function of capital intensity, \(h(T)\) should be an increasing and convex function of technology adoption parameter \(T\) in order to be able to generate heterogeneity in technologies across firms. The specific functional form that we consider is a power function \(h(T) = h_0 T^{h_1}\), where the curvature parameter \(h_1 > 1\) reflects an increasing cost of capital that requires less labor in the production process, and \(h_0\) is a scale parameter. These two parameters jointly determine the average capital intensity of exporting and non-exporting firms, which are estimated to be 0.22 and 0.24, respectively, in Stoyanov (2011) (Table 4, specification 5). Choosing \(h_0\) and \(h_1\) jointly to match these statistics for every given \(\alpha\) and \(\rho\) allows us to pin them down, and for the benchmark calibration yields the values of \(h_0 = 3.6\) and \(h_1 = 3\).

Finally, we discuss the choice of parameters \(\alpha\) and \(\rho\). As illustrated in Section 2.8, these coefficients are very important for the effect of tariff reduction on the incentives to adopt more capital-intensive technologies. If prior to trade liberalization all domestic firms used the basic technology \((\alpha = 0.22)\), then only exporters will respond to the reduction in trade barriers by switching to more capital-intensive production processes (Figure 1(a)). On the other hand, if all exporters already used the most capital-intensive technology available, then only non-exporters will react to tariff reduction by switching to more labor-intensive technologies. The latter case can be safely ruled out: in the data, higher export intensity, and hence higher productivity, is associated with the use of the more capital-intensive production process. Moreover, capital intensity of the most productive firms that export most of their output is 0.0118 higher relative to other exporters. This condition was used to obtain the parameter \(\rho\), which, for the benchmark specification, equals 0.1. As for the parameter \(\alpha\), it cannot be calibrated from the data and, given the lack of any direct evidence for the size of this coefficient, we use several different values in the simulation exercises. In the benchmark simulation \(\alpha\) is set to 0.22 to isolate the positive effect of technology adoption for exporters, and then we check how sensitive the final results are to changes in this parameter. A reduction in the variable trade costs leads to a greater reduction in the capital intensity of non-exporters when \(\alpha\) get smaller.
3.2 Steady State Distribution of Capital Intensities

The main objective of this paper is to provide a model that can explain how technological differences across firms affect aggregate productivity. In this context, it is necessary to check how close the distribution of technologies generated by the calibrated model is to real data, since these differences in technologies play a key role in the effect of technology adoption on aggregate productivity. This section describes the match between the within-industry distribution of capital-intensities implied by the model and that for French firms. It also assesses the contribution of the technology adoption effect to the ability of the model to reflect distribution patterns observed in the data.

Figure 2 shows the distribution of $\ln(K/L)$ ratio observed in the data and implied by the models with and without endogenous technology choice. Note that the log right tail of this distribution is virtually on the straight line. If there were no differences in factor prices, then the capital-labor ratio would be identical across firms and the slope of the distribution would be equal to zero. Allowing for capital price to be negatively related to productivity but assuming that all firms use the same production technology (the model with exogenous technology) can successfully replicate the right-tale distribution of capital intensities, once we adjust the slope of the former such that both lines should have the same slope to control for differences in scale. However, the distribution of capital intensities implied by that model departs from the data for firms with the lowest $K/L$ ratio.

On the other hand, the distribution of capital intensities implied by the model with endogenous technology choice very closely resembles real data. For the lowest values of $K/L$ the distribution function follows that of the model with exogenous technology choice since these are the least productive non-exporting firms. In the benchmark calibration of the model, all non-exporters use the basic technology with capital intensity equal to $\alpha$, and the difference in $K/L$ ratio comes only from differences in factor prices. The first kink in the distribution corresponds to the increase in $K/L$ due to entering a foreign market. This raises the benefit of more capital-intensive technology, because it allows for the spread the costs of technology adoption over larger quantities of output, and results in an adoption of technologies that are more productive in terms of capital. As productivity increases and the price of capital goes down, exporting firms invest more in technology adoption until capital intensity reaches its maximum. After that, higher productivity would only imply lower capital price and distribution would become parallel to that without endogenous technology choice. Therefore, the model with endogenous technology adoption by firms is more successful in generating the discrepancy in the slopes of the distribution of capital intensities and in reproducing the flatter segment for small $\ln(K/L)$ ratio.

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14 Parameters of the model are those from the benchmark specification with variable trade costs of 8%.
### 3.3 The Effect of Trade Liberalization

Now we focus on the implications of a symmetric worldwide trade liberalization, defined either as a 5% decline in import tariff or as a reduction in the variable costs of trade that leads to 9% increase in export intensity of the economy. We are particularly interested in the effect trade liberalization has on the incentive to adopt more capital-intensive technologies, and in the contribution of this effect to the aggregate productivity gain.

Panel A of Table 2 presents the absolute change in selected aggregate variables following from the reduction in variable costs of trade for the benchmark specification with no technology adoption by non-exporting firms (columns 1 and 4). The strength of the effect of technology adoption may be understood by comparing predictions of the model with endogenous technology choice and those of the model where the set of available technologies is singleton with $\alpha = 0.225$. Columns (2) and (5) of Table 2 present the effect of trade liberalization episodes in the Melitz model with exogenous production technology. Columns (3) and (6) show the fraction of the growth rate due to technology composition effect.

Liberalization of world trade decreases the average capital intensity of exporters but increases the economy-average capital intensity. The first effect is mostly due to the reduction in the productivity threshold level for exporting and the change in the export status of the most productive non-exporters that use the basic technology. For example, when variable trade costs fall by 23%, the trade-weighted average technology choice $T$ sees a decrease of 0.081 for continuing exporters. However, non-exporters continue to use the basic technology and, as a result, the output-weighted average capital intensity of the economy, $\left( \alpha + \rho \bar{T} \right)$, increases by 0.006, from 0.225 to 0.231.\(^{15}\)

Next, we can examine how these changes in technology adoption affect other aggregate variables. The decrease in tariff lowers the export price and raises the revenue of exporters. The increased attractiveness of foreign market lowers the export productivity cutoff and increases the number of exporting firms by 4.6% if there is a 5% tariff reduction, and by 21.8% when variable trade costs fall by 23%. At the same time, Columns (3) and (6) show that these effects would be 6.1% and 9.0% larger, respectively, in the model without endogenous technology. The reason is that larger exporters benefit more from adoption of more capital-intensive technologies and capture a greater share of the foreign market, raising the productivity threshold level for exporting. For the same reason, the total number of firms will fall by an additional 4.7% in the model where firms can adjust the production technology.

The model with endogenous choice of technology also has additional implications for the impact

\(^{15}\)This result follows from the first order condition for technology adoption (7): an increase in industry-average revenue increases the value of capital-intensive technologies for an average firm.
of trade costs reduction on firm-level and industry-level productivity. The average variable costs of production for non-exporters fall by 3% in response to the 23% decline in trade costs, and this effect would be 6.8% smaller (2.8%) in the model without endogenous technology choice. In the benchmark specification when all non-exporters use the basic technology, the additional increase in productivity of non-exporters comes from the increased capital-intensities of exporting firms. The following reallocation of market shares from non-exporters to exporters forces the least productive firms to shut down and raises the productivity threshold for successful entry together with the average productivity of non-exporters.

The effect of trade liberalization on the productivity of exporting firms is negative due to the expansion in export participation and the reduction in the export productivity threshold. However, tariff cuts raise the productivity of continuing exporters through adoption of more capital-intensive technologies, and together with the effect of labor reallocation from exporters to non-exporters, the technology adoption effect is responsible for a 6.1% increase in industry-average productivity.

Thus, the possibility of adjusting technological processes in response to different factor prices amplifies the long-run effects of trade on comparative advantage of exporters, identified by Melitz (2003), and contributes to the increased export-intensity of the economy. Endogeneity of technology adjustment decision by a firm also amplifies the impact of trade on industry-average productivity and output, and magnifies the total effect of trade liberalization on welfare per worker, defined as a real household income, by 6.6%.

Now consider the model where even the threshold firm has an incentive to change its production technology to a more capital-intensive one upon entry. In this case, openness to trade has an additional negative effect on aggregate productivity since non-exporting firms switch to cheaper and less capital-intensive technologies. The simulation results with $\alpha = 0.2$ are presented in Panel B of Table 2. Now the change in the average capital-intensity of both exporters and non-exporters is negative. For non-exporters the effect of the removal of the least capital-intensive firms is offset by increased incentives to use less capital-intensive technologies and by the reduction in the export productivity threshold. For firms that export, the increased capital-intensity of continuing exporters is dominated by the change in the export status of the most productive and less capital-intensive non-exporters. However, the output-weighted industry-average capital intensity increases even more than in the benchmark case for two reasons. First, the increased variable costs of production by non-exporters magnify the effect of labor and market shares reallocation toward firms that export. Second, this effect in turn increases the value of more capital-intensive technologies for exporters, increasing their output and exports, while firms that do not export shrink.

Thus, if non-exporting firms also invest in technology improvement, the effect of trade on the aggregate variables identified in the benchmark case is reinforced, which is confirmed by comparing
the last three rows of Panels A and B in Table 2. For example, comparing results for the 23% reduction in variable trade costs (Columns 4 to 6), we observe that not only does the industry-average productivity increase by 0.1% to 3.7%, but the contribution of technology adjustment activities to this effect also increases from 6.1% to 8.1%. Consequently, there is an additional increase in welfare per worker that is slightly offset by the reduction in the number of available varieties.

Therefore, reallocation of technology adjustment incentives across firms represents an additional channel for welfare gain following from tariff reduction. The series of counterfactual experiments described in this section suggest that taking into account the possibility of using different production technologies by firms with different survival probabilities can amplify the welfare and productivity gains from trade liberalization by 5 – 10%. However, these effects could be even larger had the difference in capital-intensities between exporters and non-exporters been more pronounced.16

4 Conclusions

The main objective of the paper is to offer a theoretical framework that can explain the observed differences in production technologies across firms. It extends the traditional Melitz (2003) heterogeneous firms model by allowing for endogenous technology choice by firms in an economy where survival probability and factor prices are firm-specific. The model emphasizes that trade liberalization increases the incentives for exporting firms to install more productive and more-capital-intensive technologies, which reinforces their competitive advantage relative to non-exporters and contributes further to the economy-wide productivity increase. Simulation results highlight that up to 10% of welfare gain from trade liberalization is a result of the change in production technology composition within the industry. These findings point to the need to better understand the mechanism and determinants of technology choice by firms.

16Specifically, if the initial capital intensity or capital price premium of exporters were larger, the effect of the mechanism that amplifies productivity gain from within-industry resource reallocation could be even greater. Empirical evidence suggests that these differences may in fact be stronger in other countries. For example, Bernard and Jensen (1999) report a 19% capital-labor ratio premium for US exporters, which is three times greater than that of French exporters. Alvarez and Lopez (2005) report a 60% capital-labor ratio premium for Chilean exporters.
References


Appendix

A1. Derivation of the total costs function.

The first-order condition to the following cost-minimization problem

\[ rK_j + wL_j \rightarrow \min \]
\[ \text{s.t. } A_j K_j^\alpha L_j^{1-\alpha} = D_j + F \]

is \( \frac{r}{w} \frac{1-\alpha}{\alpha} = \frac{K_j}{L_j} \). Substituting this result into output constraint and rearranging we obtain the firm-level demand for capital

\[ K_j = \frac{D_j + F}{A_j} \left( \frac{w}{r} \frac{\alpha}{1-\alpha} \right)^{1-\alpha} \] (A1)

Substituting it back to the first-order condition we obtain the demand for labor

\[ L_j = \frac{D_j + F}{A_j} \left( \frac{r}{w} \frac{1-\alpha}{\alpha} \right)^\alpha \] (A2)

Finally, the total costs function can be constructed as

\[ TC = rK_j + wL_j = \frac{D_j + F}{A_j} \left[ \left( \frac{r}{\alpha} \right)^\alpha \left( \frac{w}{1-\alpha} \right)^{1-\alpha} \right] = \lambda_j (D_j + F) \] (A3)

where \( \lambda_j = \frac{1}{A_j} \left[ \left( \frac{r}{\alpha} \right)^\alpha \left( \frac{w}{1-\alpha} \right)^{1-\alpha} \right] \) is the marginal costs of production.

A2. Derivation of the profit-maximizing choice of capital intensity (equation (7)).

With isoelastic demand function, the profit-maximizing price of each firm is a constant markup over its marginal costs: \( p_j = \frac{\sigma}{\sigma-1} \lambda_j \). Substituting this expression into profit function we obtain equation (5):

\[ \pi = (p_j - \lambda_j) q_j - \lambda_j [F + \delta (A_j) h (A_j)] = \]
\[ = \frac{1}{\sigma-1} \lambda_j q_j - \lambda_j [F + \delta (A_j) h (A_j)] = \]
\[ = \frac{1}{\sigma-1} \frac{\lambda_j}{p_j} \epsilon \bar{q} - \lambda_j [F + \delta (A_j) h (A_j)] = \]
\[ = \frac{\epsilon_j}{\sigma} - \lambda_j [F + \delta h_j] \]
Totally differentiating the above expression we obtain the FOC for $T$:

$$\frac{1}{\sigma} \frac{\partial e_j}{\partial T_j} \frac{\partial \lambda_j}{\partial T_j} [F + \delta h_j] = \delta \lambda_j \frac{\partial h_j}{\partial T_j}$$

$$\frac{\partial e_j}{\partial \lambda_j} = \frac{\partial e_j}{\partial p_j} \frac{\partial p_j}{\partial \lambda_j} = -\sigma \frac{e_j}{p_j} = -\left(\sigma - 1\right) \frac{e_j}{\lambda_j}$$

To calculate $\frac{\partial \lambda_j}{\partial T_j}$, take the natural log of both sides of the equation (6):

$$\ln \lambda_j = -\ln (A_j) + (\alpha + \rho T_j) \ln \left(\frac{r}{\alpha + \rho T_j}\right) + (1 - \alpha - \rho T_j) \ln \left(\frac{w}{1 - \alpha - \rho T_j}\right)$$

Now differentiate both sides with respect to $T_j$:

$$\frac{1}{\lambda_j} d\lambda_j = \left[ \rho \ln \left(\frac{r}{\alpha + \rho T_j}\right) + \rho - \rho \ln \left(\frac{w}{1 - \alpha - \rho T_j}\right) - \rho \right] dT_j$$

$$= \rho \ln \left(\frac{r}{w} \frac{1 - \alpha - \rho T_j}{\alpha + \rho T_j}\right) dT_j \Rightarrow$$

$$\frac{\partial \lambda_j}{\partial T_j} = \rho \lambda_j \ln \left(\frac{r}{w} \frac{1 - \alpha - \rho T_j}{\alpha + \rho T_j}\right)$$

Substituting expressions for $\frac{\partial e_j}{\partial \lambda_j}$ and $\frac{\partial \lambda_j}{\partial T_j}$ into FOC for $T_j$, we obtain equation (7):

$$\rho \left[ \frac{(1 - \sigma)}{\sigma} e(\lambda(A_j)) - \lambda(A_j)(F + \delta(A_j)h(T_j^*)) \right] \ln \left(\frac{1 - \alpha - \rho T_j^* r_j}{\alpha + \rho T_j^* w}\right) = \delta(A_j)\lambda(A_j) \frac{\partial h(T_j^*)}{\partial T_j^*}$$

**A3. Derivation of the ZCP condition (14).**

Using (5), the average profit can be expressed as a function of average revenue and marginal costs:

$$\pi(\tilde{\lambda}) = \frac{e(\tilde{\lambda})}{\sigma} - \tilde{\lambda}(A^*) \left[F + \delta h_j \left(\tilde{T}\right)\right]$$

Since average revenue can be expressed in terms of revenue of a cutoff firm, $e(\tilde{\lambda}) = \left(\frac{\tilde{\lambda}(A^*)}{\tilde{\lambda}(A^*)}\right)^{1-\sigma} e(\lambda(A^*))$, the average profit can be rewritten as

$$\pi(\tilde{\lambda}) = \frac{1}{\sigma} \left(\frac{\tilde{\lambda}(A^*)}{\tilde{\lambda}(A^*)}\right)^{1-\sigma} e(\lambda(A^*)) - \tilde{\lambda}(A^*) \left[F + \delta h_j \left(\tilde{T}\right)\right]$$

26
Finally, since \( \pi(\lambda(A^*)) = 0 \) and \( \frac{\alpha(\lambda(A^*))}{\sigma} = \tilde{\lambda}(A^*) \left[ F + \tilde{\delta} h_j \left( \tilde{T} \right) \right] \), we can write average profit as

\[
\pi(\tilde{\lambda}) = k(A^*)\tilde{\lambda}(A^*) \left[ F + \tilde{\delta} h_j \left( \tilde{T} \right) \right], \text{ where } k(A^*) = \left[ \left( \frac{\lambda(A^*)}{\tilde{\lambda}(A^*)} \right)^{\sigma} - 1 \right]
\]

Lastly, since all firms choose their production technology in upon entering the market, the average technology adoption costs will be equal to average adoption costs of new successful entrants:

\[
\tilde{\delta} h_j \left( \tilde{T} \right) = \tilde{\delta}(A^*) \frac{(1 - G(A^*))M^e}{M} h \left( \tilde{T}^e \right)
\]

\[
\pi(\tilde{\lambda}) = k(A^*)\tilde{\lambda}(A^*) \left[ F + \tilde{\delta}(A^*) \frac{(1 - G(A^*))M^e}{M} h \left( \tilde{T}^e \right) \right]
\]
Figures and Tables

Figure 1. The effect of trade openness on technology adoption and productivity

**Figure 1a.**

**Figure 1b.**
Figure 1c.
Figure 2. Distribution of capital intensities across French firms (1997-2005).
<table>
<thead>
<tr>
<th>Parameter/Function</th>
<th>Value</th>
<th>moment condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor Endowment</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Sunk entry costs</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fixed costs of production</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Elasticity of substitution</td>
<td>5</td>
<td>20% markup</td>
</tr>
<tr>
<td>Fixed costs of exporting</td>
<td>16% of export revenue</td>
<td>34% are exporters</td>
</tr>
<tr>
<td>Change in variable costs of exporting between 1997 and 2005</td>
<td>-5%</td>
<td>Observed import tariff reduction</td>
</tr>
<tr>
<td></td>
<td>-23%</td>
<td>9% increase in economy's export intensity</td>
</tr>
<tr>
<td>Distribution of productivities by new entrants</td>
<td>Pareto(3,1)</td>
<td>10% productivity advantage of exporters</td>
</tr>
<tr>
<td>Exit probability, pdf</td>
<td>Logistic(2.9; 0.08)</td>
<td>Logit model of firm's survival on productivity</td>
</tr>
<tr>
<td>Technology adoption costs function</td>
<td>Power(3.6; 3)</td>
<td>Exporters' capital intensity = 0.24</td>
</tr>
<tr>
<td>Upper bound for capital intensity</td>
<td>0.32</td>
<td>Non-exporters' capital intensity = 0.22</td>
</tr>
<tr>
<td>Lower bound on capital intensity</td>
<td>0.22; 0.20</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. The effect of trade barriers reduction, steady state comparison

<table>
<thead>
<tr>
<th>Panel A: alfa==0.22</th>
<th>5% trade costs reduction</th>
<th>23% trade costs reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Endogenous technology</td>
<td>Exogenous technology</td>
</tr>
<tr>
<td>ΔT_{nx} (Δ average technology choice of non-exporters)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>ΔT_{x} (Δ average technology choice of exporters)</td>
<td>-0.039</td>
<td>-0.081</td>
</tr>
<tr>
<td>Δ(α+ρT) (Δ industry average capital intensity)</td>
<td>0.004</td>
<td>0.005</td>
</tr>
<tr>
<td>%Δ Number of firms</td>
<td>-0.047</td>
<td>-0.049</td>
</tr>
<tr>
<td>%Δ Number of exporting firms</td>
<td>0.045</td>
<td>0.049</td>
</tr>
<tr>
<td>%Δ MC of non-exporters</td>
<td>-0.013</td>
<td>-0.012</td>
</tr>
<tr>
<td>%Δ MC of exporters</td>
<td>0.020</td>
<td>0.023</td>
</tr>
<tr>
<td>%Δ Average productivity</td>
<td>0.018</td>
<td>0.017</td>
</tr>
<tr>
<td>Δ Export intensity</td>
<td>0.023</td>
<td>0.021</td>
</tr>
<tr>
<td>%Δ Welfare per worker</td>
<td>0.016</td>
<td>0.015</td>
</tr>
</tbody>
</table>

| Panel B: alfa==0.20 |
|---------------------|--------------------------|---------------------------|
|                     | Endogenous technology   | Exogenous technology      | Relative change  | Endogenous technology | Exogenous technology | Relative change  |
| ΔT_{nx} (Δ average technology choice of non-exporters) | -0.003 | -0.005 | -0.009 |
| ΔT_{x} (Δ average technology choice of exporters) | -0.016 | -0.042 | -0.032 |
| Δ(α+ρT) (Δ industry average capital intensity) | 0.005 | 0.009 | 0.009 |
| %Δ Number of firms | -0.048 | -0.050 | 0.961 | -0.110 | -0.116 | 0.966 |
| %Δ Number of exporting firms | 0.045 | 0.048 | 0.932 | 0.214 | 0.235 | 0.910 |
| %Δ MC of non-exporters | -0.014 | -0.013 | 1.093 | -0.032 | -0.029 | 1.095 |
| %Δ MC of exporters | 0.023 | 0.027 | 0.882 | 0.096 | 0.108 | 0.889 |
| %Δ Average productivity | 0.018 | 0.017 | 1.068 | 0.037 | 0.034 | 1.081 |
| Δ Export intensity | 0.024 | 0.022 | 1.094 | 0.090 | 0.079 | 1.135 |
| %Δ Welfare per worker | 0.017 | 0.016 | 1.068 | 0.033 | 0.030 | 1.096 |

Notes: Columns (1) to (3) show the effect of tariff reduction from 8% to 3%, Columns (4) to (6) show the effect of the reduction in variable trade costs from 53% to 30%. Columns (1) and (4) show the effect of trade liberalization implied by the model with endogenous technology choice, while columns (2) and (5) show the effect implied by the Melitz model with exogenous production technology. In Columns (3) and (6) are the ratios of the change in the variable for the model with endogenous technology choice relative to the model with exogenous technology. Average technology choice, capital intensity, marginal costs, productivity and export intensity are calculated over firms using output shares as weights.