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Trade Liberalization, Reallocation, and Productivity*

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ABSTRACT

Does trade liberalization increase aggregate productivity through reallocation toward more productive firms or through productivity increases at individual firms? Using a trade model with heterogeneous firms, this paper argues that aggregate productivity gains come from firm-level productivity increases. The process of reallocation that follows trade liberalization — the exit of the least efficient firms and the movement of resources toward more efficient firms, particularly exporters — has no long-term effect on real value added per worker. This paper therefore considers how trade liberalization affects technology adoption by individual firms. If technology improvements are not costly — for example, if they occur through dynamic spillover effects — then trade liberalization has the potential to generate large increases in productivity.

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1. Introduction

Some countries experience large productivity gains following trade liberalization. Trefler (2006) argues that the 1989 Canada-U.S. Free Trade Agreement is a good case study of trade liberalization, in that it involves two developed countries that were not at the time undergoing any other major reforms. Using highly disaggregated industry data, Trefler (2006) examines the impact of trade liberalization on the Canadian industries that experienced the largest tariff cuts, where 10 percentage points was the average cut. He estimates that trade liberalization led to an increase in real value added per worker of 14 to 15 percent in these most affected industries.

Do these productivity gains occur through reallocation toward more productive firms or through productivity increases at individual firms? I answer this question from a theoretical perspective using the Melitz (2003) model of trade with heterogeneous firms. In this model, trade liberalization results in a reallocation of resources across firms. The least efficient firms exit and the most efficient non-exporters become exporters. I find, however, that this process of reallocation has no long-term effect on real value added per worker. I conclude that, for trade liberalization to substantially increase aggregate productivity, it must increase firm-level productivity.

This finding is counterintuitive at first. The intuition behind it is that the aggregation of differentiated goods requires prices and, in general equilibrium models, prices are inversely related to technological efficiency. As a result, two goods may appear to have similar value added per worker even if they are produced with very different technologies. In this case, reallocation has little or no effect on measured productivity. This is not to say that theoretical measures of real income and technological efficiency do not increase following trade liberalization — they do. But the increases in these theoretical measures are not necessarily reflected in the data-based measure of productivity. When efficiency increases at individual firms, however, measured productivity does increase, just as in the data.

How might trade liberalization generate substantial increases in firm-level productivity? I consider the role of technology adoption. In particular, I extend the model to allow for dynamic spillover effects from operating more efficient technologies. In this model, the increase in aggregate productivity following trade liberalization results from the interaction between two mechanisms: the reallocation mechanism and the spillover mechanism.

The *reallocation mechanism* is the result of two frictions facing firms that are heterogeneous in technological efficiency. Because of a per-period fixed cost of operating, the least-efficient firms may choose not to produce. Because of a sunk cost of exporting, only the most efficient firms choose to export. Following trade liberalization, the least-efficient firms exit and the most-efficient non-exporters pay the sunk cost to enter export markets. This leads to potentially large changes in a weighted average of aggregate technological efficiency.

The *spillover mechanism* is the transmission of improvements in aggregate technological efficiency to operating firms. The idea here is that firms learn from the success and failure of other firms. If a policy change such as trade liberalization results in exit of inefficient firms and expands production at the most-efficient firms, then continuing firms learn from this. They use this knowledge to adapt their own production processes, by eliminating what they now realize are inefficiencies and by trying to imitate the most successful technologies. Young (1991) considers a similar dynamic spillover effect in a trade model, except that the spillover arises from learning by doing in the production of new goods.

I also consider how trade liberalization is affected by policies that impede the process of reallocation. What happens when the government is hesitant to let inefficient firms go out of business and decides to subsidize the continued operation of inefficient firms? The productivity gains from trade liberalization are reduced by two-thirds.

Finally, I consider the equilibrium transition path from one policy regime to another. The processes of investment in new firms and in trade relationships are particularly affected during the transition. Accounting for these investments in the model as they are in the data leads to a different view of the transition than that found by Chaney (2005).

The reallocation mechanism has been studied before. Melitz (2003) studies the theoretical implications of the reallocation mechanism for stationary equilibria. Chaney (2005) considers the dynamics of trade liberalization in a version of the Melitz model. Bernard et al. (2003) also consider the reallocation mechanism and obtain measured productivity gains through a model of imperfect competition in which markups over marginal cost can vary across goods.

The findings of Atkeson and Burstein (2006) are also related to this paper. Atkeson and Burstein focus on how trade liberalization affects innovation and costly productivity improvements. They show that costly productivity improvements take a long time to pay off and have little aggregate effect. This further confirms the importance of relatively costless efficiency improvements in accounting for measured productivity gains from trade liberalization.

Kehoe and Ruhl (2006) take an approach similar to this paper in matching their model to the data. They examine the impact of terms of trade shocks on measured productivity and find that, in a standard model, terms of trade shocks have no first-order effects on measured productivity. The finding is complementary to that here.

2. Model

The model economy consists of I symmetric countries (country indices are omitted). Each country has measure $\bar{N}$ of identical consumers, each of whom is endowed with one unit of labor in every period t, $t = 0,1,\ldots$. There is a continuum of monopolistically competitive firms, each producing a unique differentiated good. The consumers own the firms and are endowed with the initial distributions of firms, $\bar{m}_0^x$ and $\bar{m}_0^d$. There is no aggregate uncertainty. The only policy distortion is an *ad valorem* tariff on imports, τ_t.

2.1. Consumers

Let Z_t be the set of goods available for consumption in a country in period t. The representative consumer has the following preferences over these goods:

$$\sum_{t=0}^{\infty} \beta^t \log\left(\int_{z \in Z_t} c_t(z)^{\rho}\, dz\right)^{1/\rho}. \tag{1}$$

Here β, $0<\beta<1$, is the consumer's discount factor; the intertemporal elasticity of substitution is one; and the intratemporal elasticity of substitution between goods is $1/(1-\rho)$. The parameter ρ satisfies $0<\rho<1$ so that goods are substitutes. Let

$$C_t = \left(\int_{z \in Z_t} c_t(z)^{\rho} \, dz \right)^{1/\rho}. \tag{2}$$

Let Z_t be partitioned into two subsets: the set of goods that are produced domestically, Z_t^d, and the set of goods that are imported, Z_t^x. The budget constraint in each period is then

$$\int_{z \in Z_t^d} p_t(z) c_t(z) \, dz + (1+\tau_t) \int_{z \in Z_t^x} p_t(z) c_t(z) \, dz = \bar{N} + \Pi_t + \mathrm{T}_t. \tag{3}$$

Here $p_t(z)$ is the price of good z, Π_t is dividend income, and T_t is the lump-sum rebate of tariff revenues. The wage serves as the numeraire in each period.

Taking prices as given, the consumer chooses consumption quantities, $\{c_t(z)\}_{z \in Zt}$, to maximize (1) subject to (3). This yields the demand function for domestically produced goods,

$$\tilde{c}_t^d(p) = \left(\frac{P_t}{p} \right)^{\frac{1}{1-\rho}} C_t, \tag{4}$$

and the demand function for imported goods,

$$\tilde{c}_t^x(p) = \left(\frac{P_t}{(1+\tau_t) p} \right)^{\frac{1}{1-\rho}} C_t. \tag{5}$$

Here P_t is the price index associated with the composite C_t:

$$P_t = \left(\int_{z \in Z_t^d} p_t(z)^{\frac{-\rho}{1-\rho}} dz + (1+\tau_t)^{\frac{-\rho}{1-\rho}} \int_{z \in Z_t^x} p_t(z)^{\frac{-\rho}{1-\rho}} dz \right)^{\frac{-(1-\rho)}{\rho}} . \quad (6)$$

Using the aggregates P_t and C_t, the budget constraint (3) can be rewritten as

$$P_t C_t = \bar{N} + \Pi_t + \mathrm{T}_t . \quad (7)$$

Let λ_t be the Lagrange multiplier on the budget constraint (7). The first-order condition with respect to C_t from the consumer's problem implies the following gross rate of interest:

$$1 + r_{t+1} = \frac{\lambda_t}{\lambda_{t+1}} = \frac{P_{t+1} C_{t+1}}{\beta P_t C_t} . \quad (8)$$

This is the market rate of interest in the economy.

2.2. Production

In each country there is a continuum of monopolistically competitive firms. Each firm produces a unique differentiated good. There is free entry of firms. The cost of entry is f^e units of labor. There is also free entry into export markets. The cost of entering export markets is f^x units of labor (since the countries are symmetric here, this is the cost of entering all export markets).

The measure of potential entrants is unbounded. Each potential entrant that pays the cost of entry draws its technological efficiency from a Pareto distribution:

$$F(a) = 1 - a^{-\eta} , \quad (9)$$

for $a \geq 1$, where $\eta > 0$. The Pareto distribution is used because it dominates in applied work (see, for example, Chaney (2006) and Eaton, Kortum, and Kramarz (2005)). The choice of one as the lower bound on the distribution is simply a normalization.

Labor is the sole factor of production. A firm's technological efficiency has two components: an idiosyncratic component and an economy-wide component. A firm's technological efficiency, a, is drawn from the probability distribution F and is constant for the life of the firm. A firm with draw a has the increasing-returns-to-scale technology

$$y(n;a) = \max\left[a\left(n - f^{p}\right),\ 0\right], \tag{10}$$

where n is the input of labor and f^{p}, $f^{p} > 0$, is the per-period fixed cost, in units of labor, of producing.

The timing within a period is as follows:

- Each firm decides whether to operate or exit. If a firm does not operate — that is, does not pay the fixed cost f^{p} — it exits irreversibly.
- Each non-exporter decides whether to pay the cost f^{x} to enter export markets in the next period.
- Each firm faces exogenous probability of death δ. This guarantees exit of firms.
- Potential firms that pay the cost of entry, f^{e}, draw their technological efficiencies.

Firms have both static and dynamic problems. A firm's static problem, maximizing period dividends, involves two decisions: the price of the good and the quantity of labor to employ. With monopolistic competition, a firm takes the consumer's demand functions (4) and (5) as given, chooses the profit-maximizing price for its good, and employs the labor necessary to meet demand at that price. A firm operating as a non-exporter solves the following problem:

$$\pi_t^d(a) = \max_{p,n} p\tilde{c}_t^d(p) - n$$
$$\text{subject to } a(n - f^p) = \tilde{c}_t^d(p) \quad . \tag{11}$$

Similarly, a firm operating as an exporter solves

$$\pi_t^x(a) = \max_{p,n} p\left(\tilde{c}_t^d(p) + (I-1)\tilde{c}_t^x(p)\right) - n$$
$$\text{subject to } a(n - f^p) = \tilde{c}_t^d(p) + (I-1)\tilde{c}_t^x(p) \quad . \tag{12}$$

Denote the choices of labor by $n_t^d(a)$ and $n_t^x(a)$. Profit maximization implies that each firm prices its good at a constant markup of $1/\rho$ over marginal cost. The pricing decision rule is

$$p(a) = \frac{1}{\rho a}. \tag{13}$$

The entry, operating, and exporting decisions of firms are dynamic. The rate at which firms discount the future depends on both the exogenous probability of survival, $1-\delta$, and the market rate of interest, r_{t+1}.

A firm that has previously paid to enter export markets chooses whether to operate or exit. An exporter's value function is

$$v_t^x(a) = \max\left[0,\ \pi_t^x(a) + \frac{1-\delta}{1+r_{t+1}} v_{t+1}^x(a)\right]. \tag{14}$$

Because of the fixed cost of operating, f, the value of operating can be negative. The decision rule for operating as an exporter is given by the indicator function

$$\chi_t^x(a) = \begin{cases} 1 & \text{if } \pi_t^x(a) + \dfrac{1-\delta}{1+r_{t+1}} v_{t+1}^x(a) \geq 0 \\ 0 & \text{otherwise} \end{cases}. \tag{15}$$

A non-exporter also chooses whether to operate or exit. If it operates, it has an additional decision: whether to pay the cost of entering export markets. Its value function is

$$v_t^d(a) = \max\left[0,\ \pi_t^d(a) + \max\left[\frac{1-\delta}{1+r_{t+1}} v_{t+1}^d(a),\ \frac{1-\delta}{1+r_{t+1}} v_{t+1}^x(a) - f^x\right]\right]. \tag{16}$$

A non-exporter's decision rule for operating is given by the indicator function

$$\chi_t^d(a) = \begin{cases} 1 & \text{if } \pi_t^d(a) + \max\left[\dfrac{1-\delta}{1+r_{t+1}} v_{t+1}^d(a),\ \dfrac{1-\delta}{1+r_{t+1}} v_{t+1}^x(a) - f^x\right] \geq 0 \\ 0 & \text{otherwise} \end{cases}. \tag{17}$$

The decision rule (17) implies a cutoff for operating, $\hat{a}_t^d$, such that a firm operates if $a \geq \hat{a}_t^d$ and exits otherwise. The cutoff $\hat{a}_t^d$ satisfies

$$\pi_t^d(\hat{a}_t^d) + \max\left[\frac{1-\delta}{1+r_{t+1}} v_{t+1}^d(\hat{a}_t^d),\ \frac{1-\delta}{1+r_{t+1}} v_{t+1}^x(\hat{a}_t^d) - f^x\right] = 0. \tag{18}$$

The cutoff is binding if $\hat{a}_t^d \geq 1$, since then any increase in the cutoff, no matter how small, would result in some firms endogenously choosing to exit.

The decision rule for becoming an exporter is given by the indicator function

$$\chi_t^e(a) = \begin{cases} 1 & \text{if } \chi_t^d(a) = 1 \text{ and } \dfrac{1-\delta}{1+r_{t+1}} v_{t+1}^x(a) - f^x \geq \dfrac{1-\delta}{1+r_{t+1}} v_{t+1}^d(a) \\ 0 & \text{otherwise} \end{cases}. \tag{19}$$

The decision rule (19) implies a cutoff for becoming an exporter, $\hat{a}_t^x$, such that a non-exporter pays the cost to become an exporter if $a \geq \hat{a}_t^x$ and remains a non-exporter otherwise. The cutoff $\hat{a}_t^x$ satisfies

$$\frac{1-\delta}{1+r_{t+1}} v_{t+1}^x\left(\hat{a}_t^x\right) - f^x = \frac{1-\delta}{1+r_{t+1}} v_{t+1}^d\left(\hat{a}_t^x\right). \tag{20}$$

The cutoff is binding if $\hat{a}_t^x > \max\left[\hat{a}_t^d,\ 1\right]$, since then not all firms choose to export.

There is free entry of firms, and firms enter as non-exporters. The cost of entry is f^e units of labor. The free-entry condition is

$$\frac{1}{1+r_{t+1}} \int v_{t+1}^d\left(a\right) F\left(da\right) - f^e \leq 0, \ \ = 0 \text{ if } e_t > 0\,. \tag{21}$$

Firms enter until the net expected value of entry is zero. The inequality in (21) reflects the constraint that $e_t \geq 0$.

The state variables in the model are the distributions of firms by efficiency and aggregate productivity. It is convenient to define four cumulative distributions of firms. Let the distributions of firms that have the option of operating in period t be m_t^x for exporters and m_t^d for non-exporters. Given these distributions, apply the operating decision rules to obtain the distributions of firms that choose to operate:

$$\mu_t^x\left(a\right) = \int_1^a \chi_t^x\left(\alpha\right) m_t^x\left(d\alpha\right) \tag{22}$$

$$\mu_t^d\left(a\right) = \int_1^a \chi_t^d\left(\alpha\right) m_t^d\left(d\alpha\right). \tag{23}$$

The consumer is endowed with the initial distributions of firms, $\bar{m}_0^x$ and $\bar{m}_0^d$. The distributions of firms then evolve as follows:

$$m_{t+1}^x(a) = (1-\delta)\left(\mu_t^x(a) + \int_1^a \chi_t^e(\alpha)\mu_t^d(d\alpha)\right) \tag{24}$$

$$m_{t+1}^d(a) = (1-\delta)\int_1^a \left(1-\chi_t^e(\alpha)\right)\mu_t^d(d\alpha) + e_t F(a). \tag{25}$$

2.3. Equilibrium

Definition 1. Given a sequence of tariffs, $\{\tau_t\}$, and initial distributions of firms, $\bar{m}_0^x$ and $\bar{m}_0^d$, an *equilibrium* for this economy is the following sequences for each country: sets of goods $\{Z_t, Z_t^d, Z_t^x\}$, consumption quantities $\{c_t(z)\}_{z\in Z_t}$, prices of goods $\{p_t(z)\}_{z\in Z_t}$, dividend income $\{\Pi_t\}$, transfers $\{\mathrm{T}_t\}$, interest rates $\{r_{t+1}\}$, measures of entrants $\{e_t\}$, distributions of firms $\{\mu_t^x, \mu_t^d, m_t^x, m_t^d\}$, and, for each firm type, labor and pricing decision rules $\{n_t^x, n_t^d, p_t\}$, dividends $\{\pi_t^x, \pi_t^d\}$, value functions $\{v_t^x, v_t^d\}$, and operating and exporting decision rules $\{\chi_t^x, \chi_t^d, \chi_t^e\}$ such that:

- Given $\{Z_t, Z_t^d, Z_t^x, \Pi_t, \mathrm{T}_t\}$ and $\{p_t(z)\}_{z\in Z_t}$, the consumer chooses $\{c_t(z)\}_{z\in Z_t}$ to maximize (1) subject to (2) and (3).
- Given the demand functions that come from solving the consumer's problem, (4) and (5), firms choose $\{n_t^x, n_t^d, p_t\}$ to solve the maximization problems in (11) and (12). Dividends $\{\pi_t^x, \pi_t^d\}$ satisfy (11) and (12).
- The price of each good is aligned with the pricing decision rule of the type of firm that produces it: $p_t(z;a) = p_t(a)$.

- Interest rates $\{r_{t+1}\}$ satisfy (8), where $\{C_t\}$ is given by (2) and $\{P_t\}$ is given by (6).
- The decision rules $\{\chi_t^x, \chi_t^d, \chi_t^e\}$ solve the maximization problems in (14) and (16). The value functions satisfy (14) and (16).
- The free-entry condition (21) is satisfied.
- The distributions of firms $\{\mu_t^x, \mu_t^d, m_t^x, m_t^d\}$ satisfy (22) through (25).
- Tariff revenues are rebated to the consumer as a lump sum:

$$\mathrm{T}_t = \tau_t \int_{z \in Z_t^x} p_t(z) c_t(z) dz . \tag{26}$$

- The consumer receives the dividend income:

$$\Pi_t = \int \left(\pi_t^d(a) \mu_t^d(da) + \pi_t^x(a) \mu_t^x(da) - f^x \chi_t^e(a) \mu_t^d(da) \right) - f^e e_t . \tag{27}$$

- The labor market clears:

$$\int \left(n_t^d(a) \mu_t^d(da) + n_t^x(a) \mu_t^x(da) + f^x \chi_t^e(a) \mu_t^d(da) \right) + f^e e_t = \bar{N} . \tag{28}$$

- International payments are balanced:

$$\int_{z \in Z_t^d} p_t(z) \left(y_t(z) - c_t(z) \right) dz = \int_{z \in Z_t^x} p_t(z) c_t(z) . \tag{29}$$

A convenient way of analyzing the long-term effects of trade liberalization is to compare stationary equilibria of the economy at various levels of a constant tariff $\bar{\tau}$.

Definition 2. Given $\bar{\tau}$, a *stationary equilibrium* for this economy is an equilibrium, as defined above, in which:

- $\tau_t = \bar{\tau}$ for all t

- $\overline{m}_0^x$, and $\overline{m}_0^d$ are such that the state variables of the model, $\left\{\mu_t^x, \mu_t^d\right\}$, are constant over time.

3. Measurement

In this section I show how to measure productivity in the model as it is measured in the data — as real value added per worker. I then contrast this with a theoretical index of real income.

The relevant measure of productivity in the model is real value added per worker in the production of differentiated goods. Value added in the production of differentiated goods at current prices is

$$y_t = \int_{z \in Z_t^d} p_t\left(z\right) y_t\left(z\right) dz \,. \tag{30}$$

The standard way of obtaining real value added is to value output at base-period prices. Value added at period-T prices in the production of differentiated goods is

$$Y_t = \int_{z \in Z_t^d} p_T\left(z\right) y_t\left(z\right) dz \,. \tag{31}$$

Labor is the sole factor of production in the model and its supply is fixed at $\overline{N}$, so measured productivity is $Y_t / \overline{N}$.

There is a measurement problem here: What is the base-period price of a good that was not produced in the base period? This is an issue that must be confronted in the data as well, so national accounting procedures have been developed to deal with this problem. The method recommended in guidelines for the United Nations System of National Accounts is the following: To obtain the base-period price of a new good, deflate the current price of the good by the price index of a basket of similar goods that were produced in both the current and base periods.

To see how this works in the model, pick some basket of "similar" goods produced in both the current and base periods, $\tilde{Z}$ (the final result will be independent of the particular goods chosen). A Laspeyres price index is

$$\tilde{P}_t = \frac{\int_{\tilde{Z}} p_t(z) y_T(z) dz}{\int_{\tilde{Z}} p_T(z) y_T(z) dz} \times 100 . \tag{32}$$

The price index is 100 in the base year. For now the composition of the basket $\tilde{Z}$ is unimportant, as (32) simply reduces to $\tilde{P}_t = 100$. The period-T price of a good z not produced in period T is then

$$p_T(z) = \frac{p_t(z)}{\tilde{P}_t} \times 100 . \tag{33}$$

The distinction between $\tilde{P}_t$ and P_t is important. The former is a data-based price index; the latter is a theoretical price index. The theoretical price index has a changing basket of goods, uses consumer prices (including tariffs), and depends on the model parameter ρ.

The measurement of value added per worker in the data contrasts sharply with the theoretical measurement of real income. To obtain a theoretical index of real income, take income as given by the budget constraint (7) and divide it by the price index P_t. This gives

$$C_t = \frac{\bar{N} + \Pi_t + \mathrm{T}_t}{P_t} . \tag{34}$$

This is an ideal real income index, as preferences are identical and homothetic and C_t is a homogeneous-of-degree-one representation of period utility. Interestingly, (31) and (34) have little relation to one another. Moreover, the ideal real income index gives a different picture than taking income from the data and dividing by a price index such as the CPI. This is a point that Feenstra (1994) also makes.

How does C_t relate to the aggregate efficiency index $\bar{a}_t$? Plugging in (13), the aggregate price index is

$$P_t = \left(\int (\rho a)^{\frac{\rho}{1-\rho}} \left(\mu^d (da) + \mu^x (da) \right) + (1+\tau_t)^{\frac{-\rho}{1-\rho}} \int (\rho a)^{\frac{\rho}{1-\rho}} \mu^x (da) \right)^{\frac{-(1-\rho)}{\rho}}. \quad (35)$$

Then, after some algebra,

$$P_t = \frac{1}{\rho v_t^{(1-\rho)/\rho} \bar{a}_t}, \quad (36)$$

where v_t is the measure of varieties available to the consumer. Thus real income (34) can be expressed as

$$C_t = \rho v_t^{\frac{1-\rho}{\rho}} \bar{a}_t \left(\bar{N} + \Pi_t + \mathrm{T}_t \right). \quad (37)$$

So C_t is directly affected by the aggregate efficiency index, $\bar{a}_t$, but is affected by a number of other factors as well.

4. To What Extent Can Reallocation Account for Productivity Gains?

In this section I analyze the long-term effects of trade liberalization by comparing stationary equilibria. I begin with the model just laid out, which I refer to as the benchmark model, and then consider two variations.

In the model there are two important efficiency cutoffs for firms: the cutoff for operating, $\hat{a}^d$, and the cutoff for exporting, $\hat{a}^x$, as given by (18) and (20). Trade liberalization changes these cutoffs and therefore changes the efficiency distributions of firms. In particular, the least-efficient firms are driven out and the most-efficient non-exporters become exporters, as in Melitz (2003). That is, comparing stationary equilibria and assuming that both cutoffs bind, trade liberalization increases $\hat{a}^d$ and decreases $\hat{a}^x$.

4.1. Static Version of the Model: An Analytical Result

To obtain an unambiguous analytical result on trade liberalization and measured productivity, I consider the stationary equilibrium of the model in the limiting case where β approaches one (this is also the case considered by Melitz (2003) and Chaney (2005)). In this static version of the model, the consumer simply maximizes the consumption index C, as given by (2), every period. The reason for this assumption is given by the following lemma:

Lemma 1. In a stationary equilibrium with $\beta \to 1$, $\Pi = 0$.

Proof. We want to show that

$$\int \left(\pi^d(a)\mu^d(da) + \pi^x(a)\mu^x(da) - f^x\chi^e(a)\mu^d(da) \right) - f^e e = 0. \tag{38}$$

By the free-entry condition (21), the present discounted value of entry is

$$\int v^d(a)F(da) = f^e. \tag{39}$$

Let M be the measure of operating firms. The present discounted value of entry is then

$$f^e = \frac{1 - F\left(\hat{a}^d\right)}{\delta M} \int \left(\pi^d(a)\mu^d(da) + \pi^x(a)\mu^x(da) - f^x\chi^e(a)\mu^d(da) \right). \tag{40}$$

In a stationary equilibrium, exit of operating firms must equal entry of operating firms, so $\delta M = \left(1 - F\left(\hat{a}^d\right)\right)e$. Substituting this in (40), we obtain (38). ■

If there is discounting by the consumer, then $\Pi > 0$, as there is a positive real interest rate and the consumer earns a positive net return on investment in firms. Repeating the same procedure as in the proof above, for a stationary equilibrium with $0 < \beta < 1$,

$$\Pi = \left(\frac{1}{\beta} - 1\right)\left(\pi^d(a)\mu^d(da) + \pi^x(a)\mu^x(da) - f^x \chi^e(a)\mu^d(da)\right). \tag{41}$$

When operating profits increase following trade liberalization, Π also increases. I consider this case, with a discount factor consistent with real interest rates in the data, in the numerical experiment below, but first I establish the main analytical result of the paper.

Proposition 1. In a stationary equilibrium with $\beta \to 1$, the level of the tariff has no effect on real value added per worker in the production of differentiated goods.

Proof. By Lemma 1, $\Pi = 0$. Subtracting tariff revenue from both sides of the budget constraint, we have

$$\int_{z \in Z_t^d} p_t(z) c_t(z) dz + \int_{z \in Z_t^x} p_t(z) c_t(z) dz = \bar{N}. \tag{42}$$

The balance-of-payments condition is

$$\int_{z \in Z_t^d} p_t(z)\left(y_t(z) - c_t(z)\right) dz = \int_{z \in Z_t^x} p_t(z) c_t(z). \tag{43}$$

Combining (42) and (43), we have

$$\int_{z \in Z_t^d} p_t(z) y_t(z) dz = \bar{N}. \tag{44}$$

Choose a base period T. A good $z \in Z_t^d$ was either produced in period T or not. If the good was produced in period T, then its base-period price is simply $p_T(z)$. The price of a good does not depend on time: $p_t(z;a) = 1/(\rho a)$. Thus $p_T(z) = p_t(z)$. If a good was not produced in period T, then we apply the deflation method used in (33) to obtain a price consistent with the base period. The result is that $p_T(z) = p_t(z)$. Real value added in the production of differentiated goods is therefore the same as (44):

$$Y_t = \int_{z \in Z_t^d} p_T(z) y_t(z) dz = \int_{z \in Z_t^d} p_t(z) y_t(z) dz = \bar{N}. \tag{45}$$

Then real value added per worker is $Y_t / \bar{N} = 1$. ■

That is, even in the extreme case of moving from autarky to free trade, there are no long-term measured productivity gains from trade liberalization here, despite the dramatic reallocation that would occur as resources are moved away from the least-efficient firms and toward the most-efficient firms.

What explains this highly counterintuitive result? There are two factors at work. The first has to do with aggregation and prices. The second has to do with economies of scale.

First, the aggregation of goods to obtain value added of course requires prices. In general equilibrium models, however, prices are inversely related to technological efficiency. For intuition it may be helpful to consider value added per worker at an individual firm. If the firm has technological efficiency a and is not currently paying any sunk costs, then value added per worker at the firm is

$$\frac{p_t(a) y_t(a)}{n_t(a)} = \frac{\left(1/(\rho a)\right) a \left(n_t(a) - f^p\right)}{n_t(a)} = \frac{n_t(a) - f^p}{\rho n_t(a)}. \tag{46}$$

If it were the case that $f^p = 0$, then (46) would not depend on a whatsoever, as it would reduce to $1/\rho$. In this case, reallocation of labor across firms of heterogeneous efficiency would have no impact on aggregate value added per worker, even though the reallocation would matter for welfare and aggregate efficiency. (This is a feature of another common model of trade, the Ricardian model with a continuum of goods, as in Dornbusch, Fischer, and Samuelson (1977). Bernard et al. (2003) point this out and propose modifying the model of Eaton and Kortum (2002) to include a form of imperfect competition such that there are some differences in value added per worker across goods.)

Second, with the economy of scale here, $f^p > 0$, trade liberalization has two opposing effects on measured productivity across firms. Since n_t is increasing in a, firms of higher efficiency have higher value added per worker. This allows the model to match the fact, stressed by Bernard et al. (2003), that there are large differences in measured productivity across producers, with exporters tending to have higher measured productivity. How does trade liberalization change measured productivity across firms? It amplifies this scale economy. As Melitz (2003) shows, non-exporters experience employment losses and exporters experience employment gains. Thus measured productivity increases at exporters and decreases at non-exporters. The partial-equilibrium intuition that, following liberalization, reallocation toward exporters must increase measured productivity is therefore misleading.

The result in this section is perhaps surprising. The message here is not that trade liberalization is a misguided policy reform under these assumptions — on the contrary, it leads to welfare gains, and reallocation plays an important role — but rather that these gains are not well reflected in data-based measures of productivity. I demonstrate this quantitatively in the next subsection.

4.2. Model Dynamics: An Illustrative Numerical Experiment

To illustrate the long-term effects of trade liberalization in the model, I conduct the numerical experiment of eliminating a 20 percent tariff between two countries and then compare the stationary equilibria (I show the transition in the next section).

4.2.1. Parameterization

The parameters of the model are not calibrated to any particular trade liberalization episode, but they are chosen to be plausible. The parameters of the model are $\bar{N}$, β, ρ, δ, f^p, f^e, f^x, and η. As a normalization, I set $\bar{N}$ to one. The length of a period is one year, so I set $\beta = 0.96$ to match an annual real interest rate of 4 percent. I set $\rho = 0.5$ so that the consumer's elasticity of substitution between goods, $1/(1-\rho)$, is 2. This value is higher than estimates of the elasticity of substitution at business-cycle frequencies and lower than estimates based on trade liberalization episodes. But Ruhl (2003) finds that a model with heterogeneous firms and sunk costs of exporting goes far in reconciling the differing estimates when the elasticity of substitution in the model is 2. I set f^e to one and then choose f^p and f^d relative to this. First I set δ to 5 percent, consistent with depreciation rates in the data. Then I initially let the exogenous exit probability δ be the only source of plant exit. That is, I choose f^p so that $\hat{a}^d$ matches the lower bound of the distribution of draws, which is one here. I set f^x so that exports are initially 20 percent of output. Finally, Eaton, Kortum, and Kramarz (2005) find that setting the curvature parameter on the Pareto distribution, η, to 1.5 is consistent with data on the sales of French firms in a trade model of this sort. Table 1 summarizes the parameterization.

4.2.2. Quantitative Results

Table 3 shows the effect of trade liberalization in the benchmark model. As just noted earlier, the only reason there is any increase in measured productivity at all is that I have set $\beta = 0.96$ to generate a positive real interest rate in line with the data. The increase in real income following trade liberalization is small, and the increase in measured productivity is even smaller.

4.3. Analysis of the Transition

One of the interesting features of the transition following trade liberalization is that there is a shift in the allocation of labor. New firms temporarily cease to be developed and labor is instead diverted toward developing trade relationships so that firms can access export markets. This has important implications for measured productivity that differ from previous theoretical findings (such as those of Chaney (2005)). In particular, properly accounting for investment shows how, in the aggregate, the transition following trade liberalization initially leads to productivity drops. To understand the aggregate implications I fully specify the national income and product accounts for this economy (previously I only considered value added in the production of differentiated goods), but first I revisit the original numerical example and discuss the transition path.

I consider the same experiment as before, the elimination of a 20 percent tariff on imports. The policy change is unexpected. In period $t = 0$, the economy is in the stationary equilibrium with $\bar{\tau} = 0.2$. In period $t = 1$, the economy is unexpectedly liberalized and begins converging toward the stationary equilibrium with $\bar{\tau} = 0$. I provide the computational algorithm in the appendix.

First I consider the effect of the transition on welfare. Up to this point, I have focused on stationary equilibria. In the stationary equilibrium without a tariff, welfare is 18.5 percent higher than in the stationary equilibrium with a 20 percent tariff. To what extent does accounting for the transition reduce this welfare gain? If an economy has a 20 percent tariff in period 0 and the tariff is unexpectedly and permanently removed in period 1, then social welfare increases by 13.9 percent. Table 5 summarizes these findings.

Figures 1 through 4 illustrate the transition path for various measures of productivity and for exports. There is fairly rapid convergence, so I plot only the first ten periods following liberalization.

4.3.1. The National Income and Product Accounts

The measurement of investment in the model matters for the measurement of GDP. Costs of developing new firms and entering export markets are modeled here as sunk costs denominated in units of labor. This seems like a reasonable abstraction with respect to sunk costs of entering export markets: The manager of the firm assembles a team of people who have the task of adapting the product to various foreign markets and then introducing it to those markets through advertising, branding, distribution networks, and the like.

Setting up a new firm, however, typically requires a substantial investment in structures and equipment. In this sense, it makes more sense to think about the sunk cost of entry as the purchase of fixed capital. This need not change the model: Simply assume that producing one unit of fixed capital requires one unit of labor and that entry requires the purchase of f^e units of fixed capital. It does, however, change the accounting of value added.

Here I specify the national income and product accounts for this economy. In the model, as in the data, there are three ways to calculate GDP. The output approach sums value added and taxes on imports:

$$y_t = \int_{z \in Z_t} p_t(z) y_t(z) dz + f^e e_t + \tau_t \int_{z \in Z_t^x} p_t(z) c_t(z) dz . \tag{47}$$

(I now use y_t to refer to GDP, whereas earlier I used y_t to refer to value added in the differentiated goods sector.) The expenditure approach sums spending on final goods and services and net exports:

$$\begin{aligned} y_t = & \int_{z \in Z_t^d} p_t(z) c_t(z) dz + (1+\tau_t) \int_{z \in Z_t^x} p_t(z) c_t(z) dz + f^e e_t \\ & + \left(\int_{z \in Z_t^d} p_t(z) \left(y_t(z) - c_t(z) \right) dz - \int_{z \in Z_t^x} p_t(z) c_t(z) \right) \end{aligned} . \tag{48}$$

Because trade is balanced, the final term, net exports, is zero. The income approach sums wages, gross operating surplus, and transfers:

$$y_t = \bar{N} + \Pi_t + f^e e_t + \mathrm{T}_t . \tag{49}$$

All approaches give the same measure of GDP.

Measuring productivity across time requires a measure of real GDP. Consistent with the data, I calculate real GDP as GDP at base-period prices. Real GDP at period-T prices is

$$\int_{z \in Z_t} p_T(z) y_t(z) dz + f^e e_t + \tau_T \int_{z \in Z_t^d} p_T(z) c_t(z) dz . \qquad (50)$$

If the tariff changes over time, then the path of real GDP will differ depending on the choice of a base year. For the numerical calculations, I simply focus on value added (that is, I choose T to be a period in which $\tau_T = 0$).

4.3.2. Numerical Experiment with Measured Investment

I again conduct the same numerical experiment that has been the focus of this paper and this time examine the transition path with particular attention to the use of labor over time.

As Figure 5 shows, the amount of labor devoted to sunk costs, as opposed to production, does not vary that much over the transition, but the allocation of labor between developing new firms and developing trade relationships changes drastically. In the period following liberalization, investment in new firms actually falls to zero as firms are retooling to become exporters.

This diverts a great deal of labor from producing the investment good, and production of the investment good generates value added. As Figure 6 shows, this initially leads to a large drop in aggregate value added per worker. This drop is greatly exaggerated since I have not fully modeled the aggregate economy — some of the investment goods would come from nontradable sectors, such as construction, that are not considered here — but it does give a sense of how the process of reallocation can initially decrease aggregate productivity.

5. Trade Liberalization and Technology Adoption

Here I extend the model to incorporate dynamic spillover effects from operating more efficient technologies. Economy-wide efficiency evolves according to an aggregate index of technological efficiencies operated in the previous period. First I define an *efficiency index for domestic production*, a weighted average of operating firms' technological efficiencies:

$$\overline{a}_t^d = \left(\frac{1}{1 - F\left(\hat{a}_t^d\right)} \int_{\hat{a}_t^d}^{\infty} a^{\frac{\rho}{1-\rho}} F\left(da\right) \right)^{\frac{1-\rho}{\rho}} . \tag{51}$$

Next I define an *efficiency index for export production,* a weighted average of exporting firms' technological efficiencies:

$$\overline{a}_t^x = \left(\frac{1}{1 - F\left(\hat{a}_t^x\right)} \int_{\hat{a}_t^x}^{\infty} a^{\frac{\rho}{1-\rho}} F\left(da\right) \right)^{\frac{1-\rho}{\rho}} . \tag{52}$$

Finally, I define an *aggregate efficiency index*, which combines the indices for domestic production efficiency and export production efficiency as follows:

$$\overline{a}_t = \left(\omega_t \left(\overline{a}_t^d\right)^{\frac{\rho}{1-\rho}} + \left(1 - \omega_t\right)\left(1 + \tau_t\right)^{\frac{-\rho}{1-\rho}} \left(\overline{a}_t^x\right)^{\frac{\rho}{1-\rho}} \right)^{\frac{1-\rho}{\rho}} , \tag{53}$$

where ω_t is the share of total varieties produced domestically. The presence of τ_t in (53) reflects the way in which the tariff affects market shares, as can be seen from comparing (4) and (5). Taking s_0 as given, economy-wide efficiency evolves according to

$$s_{t+1} = \overline{a}_t . \tag{54}$$

Changes in economy-wide efficiency have a multiplicative effect on an individual firm's operating efficiency, as shown in (10).

Labor is the sole factor of production. A firm's technological efficiency has two components: an idiosyncratic component and an economy-wide component. A firm's *idiosyncratic efficiency*, a, is drawn from the probability distribution F and is constant for the life of the firm. *Economy-wide efficiency*, s_t, evolves according to a dynamic spillover mechanism specified later. A firm with idiosyncratic efficiency draw a has the increasing-returns-to-scale technology

$$y_t(n;a) = \max\left[s_t a\left(n - f^p\right),\ 0\right]. \tag{55}$$

5.1. Illustrative Numerical Experiment

Table 2 compares the stationary equilibrium of the model with a 20 percent tariff and the stationary equilibrium with no tariff.

Here measured productivity captures most of the change in real income. It increases by 15.5 percent, while real income increases by 18.9 percent. The theoretical and empirical measures are similar in magnitude as a result of the spillover.

The aggregate efficiency index, which drives the spillover, increases by 13.7 percent. Table 2 also shows the components of the aggregate efficiency index, as given by (53). Initially domestic production efficiency is 94.9 percent of aggregate efficiency, export production efficiency is 282.1 percent of aggregate efficiency, and imports are 10.8 percent of the available varieties. Following trade liberalization, as a result of the increase in $\hat{a}^d$, the domestic production efficiency index increases from 94.9 to 102.6. At the same time, because of the decrease in $\hat{a}^x$, the export production efficiency index decreases from 282.1 to 228.5. But the share of varieties imported increases to 17.7 percent.

Labor is used in three ways: for production, for paying sunk costs of entry, and for paying sunk costs of exporting. The allocation of labor among these three activities does not change much as a result of trade liberalization. The main change is that about 2 percent of the labor force is shifted from producing goods to paying sunk costs of exporting.

Following trade liberalization, there is a 13.2 percent decrease in the number of firms. This aspect of the model is consistent with findings in Head and Ries (1999) for Canada and Pavcnik (2002) for Chile. Both studies find substantial firm exit following trade liberalization. The share of firms that export increases from 12.1 percent to 21.5 percent. There is a large increase in exports, from 20 percent of output to 32.3 percent of output. This is primarily driven by the fact that the share of firms exporting increases from 12.1 percent to 21.5 percent. This is what Kehoe and Ruhl (2002) call the "new goods margin in international trade" — many firms that were not previously exporting their goods find it worthwhile, after trade liberalization, to pay the cost of entering export markets. Kehoe and Ruhl (2002) find strong empirical support for movement on this margin following trade liberalization.

5.2. Trade Liberalization with Subsidies to Firms

The productivity gains from trade liberalization in this model rest on reallocation and especially on the exit of inefficient firms. What if countries adopt policies that impede this process of reallocation? Kambourov (2006) shows, for instance, that labor market policies such as firing costs can disrupt the process of reallocation and substantially reduce the gains from trade liberalization. In this section I consider a related policy, government subsidies to operating firms. The results here are complementary to those of Kambourov (2006). These sorts of results help to account for the phenomenon that some countries seem to have benefited little from trade liberalization. Kambourov (2006) points out that this is especially true of many countries in Latin America, Chile being a notable exception.

In the model here, trade liberalization leads to the exit of inefficient firms. Suppose, however, that the government is reluctant to let inefficient firms go out of business and decides to provide subsidies to those firms that experience operating losses following trade liberalization. These subsidies are financed by a lump-sum tax on the consumer.

In terms of the mechanics of the model, I am assuming that if $\chi_0^d(a)=1$, then the government ensures $\chi_t^d(a)=1$ by providing an operating subsidy equal to $\max\left[0,\ -\pi_t^d(a)\right]$ for all $t=1,2,\ldots$.

How does this affect the gains from trade liberalization?

Table 4 compares liberalization in the model without the subsidy to liberalization in the model with the subsidy. The operating subsidy substantially reduces the potential gains from trade liberalization. Measured productivity still increases, but only by 5.1 percent, a decrease of two-thirds from the 15.3 percent increase without the subsidy. Similarly, real income increases, but by 7.0 percent as compared to 18.5 percent without the subsidy. As a result of inefficient firms not exiting, the efficiency index for domestic production does not change following liberalization. The only source of efficiency gains is reallocation toward exporters. Thus aggregate efficiency increases by 4.5 percent as compared to 13.7 percent before. The only other major change concerns the number of firms, which decreases by only 5.1 percent with the subsidy, much less than the 13.2 percent decrease without it.

6. Conclusion

This paper has presented a dynamic general equilibrium model of trade that accounts for measured productivity gains following trade liberalization. The mechanism behind this result is the interaction between the reallocation toward firms of higher efficiency and a production externality that transmits improvements in aggregate technological efficiency to operating firms.

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APPENDIX: COMPUTATIONAL ALGORITHM

Compute the stationary equilibrium of the economy under each policy regime. In period $t = 0$, the economy is in the initial stationary equilibrium. This gives the initial state during the transition, $\{s_1, m_1^x, m_1^d\}$. Assume that the economy reaches the new stationary equilibrium in period $T+1$, where T is large. Then use Newton's method to solve a system of $4T$ equations given $4T$ variables:

- Guess $\{P_t\}_{t=1}^T$, $\{r_{t+1}\}_{t=1}^T$, $\{e_t\}_{t=1}^T$, and $\{s_{t+1}\}_{t=1}^T$.
- Take P_{T+1} and C_{T+1} as given. Working backward from period T, let

$$C_t = \frac{P_{t+1} C_{t+1}}{\beta P_t \left(1 + r_{t+1}\right)}. \tag{56}$$

- Take v_{T+1}^x and v_{T+1}^d as given. Working backward from period T, solve for the value functions, (14) and (16).
- Given $\{m_1^x, m_1^d\}$, solve for the distributions, (22) through (25).
- Check whether the following conditions hold for periods $t = 1, ..., T$:

$$\int \left(n_t^d(a) \mu_t^d(da) + n_t^x(a) \mu_t^x(da) + f^x \chi_t^e(a) \mu_t^d(da) \right) + f^e e_t - \bar{N} = 0 \tag{57}$$

$$C_t - \left(\int_{z \in Z_t} c_t(z)^\rho \, dz \right)^{1/\rho} = 0 \tag{58}$$

$$\frac{1}{1 + r_{t+1}} \int v_{t+1}^d(a) F(da) - f^e + \zeta \min\left(e_t, 0\right)^2 = 0 \tag{59}$$

$$s_{t+1} - \bar{a}_t = 0 . \tag{60}$$

In (59), v_{T+1}^d is taken as given and $\zeta \gg 0$ is a penalty parameter to computationally deal with the constraint that $e_t \geq 0$.

- If the conditions hold, stop. If the conditions do not hold, use Newton's method to obtain new guesses.

TABLE 1

Summary of the Parameterization

Parameter	Value	Chosen to Match
$\bar{N}$	1	Normalization
β	0.96	Interest rate of 4 percent
ρ	0.5	Elasticity of substitution of 2 (Ruhl 2003)
f^e	1	Other costs are relative to this
f^p	0.06	$\hat{a}^d = 1$
f^x	1.6	Exports are 20 percent of output
δ	0.05	Exit rate of 5 percent
η	1.5	Eaton, Kortum, and Kramarz (2005)

TABLE 2

Stationary Equilibrium: Benchmark Model

Statistic	20 Percent Tariff	No Tariff
Real income index	100.0	104.2
Measured productivity index	100.0	101.4
Aggregate efficiency index	100.0	113.7
Non-export efficiency rel. to aggregate	94.9	102.6
Export efficiency rel. to aggregate	282.1	228.5
Imported varieties as a percent of total	10.8	17.7
Labor used in production (percent)	78.9	77.1
Labor used for sunk costs of entry	17.7	17.6
Labor used for sunk costs of exporting	3.4	5.3
Number of firms (index)	100.0	86.8
Percent of firms that export	12.1	21.5
Exports as a percent of output	20.0	32.3

TABLE 3

Comparing the Benchmark Model to the Model with the Spillover

Statistic	20 Percent Tariff	No Tariff with Spillover	No Tariff, No Spillover
Real income index	100.0	118.5	104.2
Measured productivity index	100.0	115.3	101.4
Aggregate efficiency index	100.0	113.7	113.7
Non-export efficiency rel. to aggregate	94.9	102.6	102.6
Export efficiency rel. to aggregate	282.1	228.5	228.5
Imported varieties as a percent of total	10.8	17.7	17.7
Labor used for production	78.9	77.1	77.1
Labor used for sunk costs of entry	17.7	17.6	17.6
Labor used for sunk costs of exporting	3.4	5.3	5.3
Number of firms (index)	100.0	86.8	86.8
Percent of firms that export	12.1	21.5	21.5
Exports as a percent of output	20.0	32.3	32.3

TABLE 4

The Effect of Operating Subsidies on the Outcome of Trade Liberalization

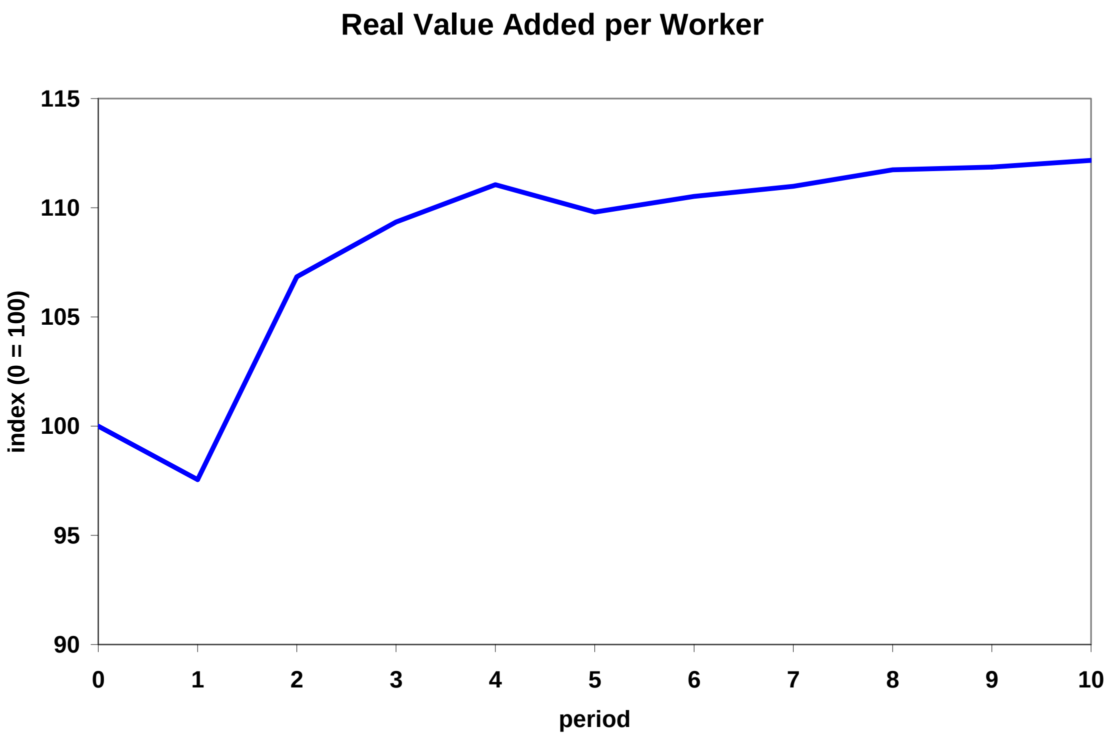
Statistic	20 Percent Tariff	No Tariff	Subsidies, No Tariff
Real income index	100.0	118.5	107.0
Measured productivity index	100.0	115.3	105.1
Aggregate efficiency index	100.0	113.7	104.5
Domestic production efficiency	94.9	102.6	94.9
Export production efficiency	282.1	228.5	228.5
Imported varieties as a percent of total	10.8	17.7	15.8
Labor used for production	78.9	77.1	78.1
Labor used for sunk costs of entry	17.7	17.6	16.8
Labor used for sunk costs of exporting	3.4	5.3	5.1
Number of firms (index)	100.0	86.8	94.9
Percent of firms that export	12.1	21.5	18.7
Exports as a percent of output	20.0	32.3	31.1

TABLE 5

Dynamic Welfare Analysis with the Spillover

Regime	**Welfare**
Stationary equilibrium with 20 percent tariff	100.0
Stationary equilibrium with no tariff	118.5
Liberalization with transition	113.9

FIGURE 1



Real Value Added per Worker
115
110
105
100
95
90
index (0 = 100)
0
1
2
3
4
5
6
7
8
9
10
period

FIGURE 2

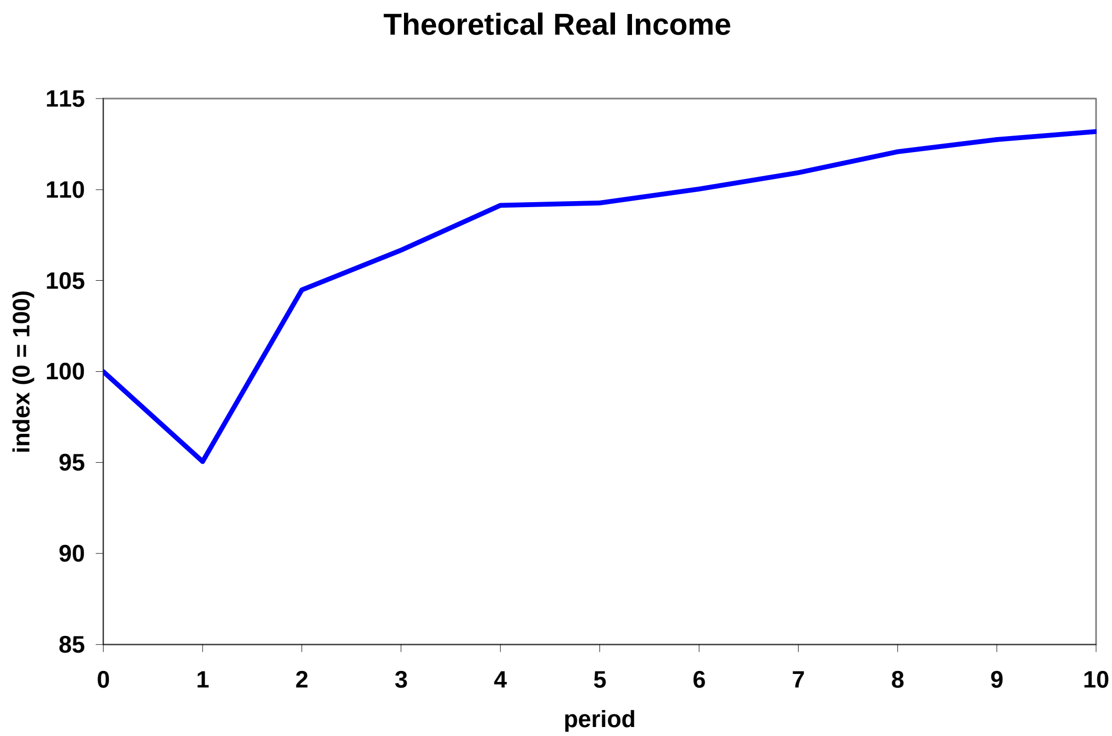

Theoretical Real Income
115
110
105
100
95
90
85
index (0 = 100)
0
1
2
3
4
5
6
7
8
9
10
period

FIGURE 3

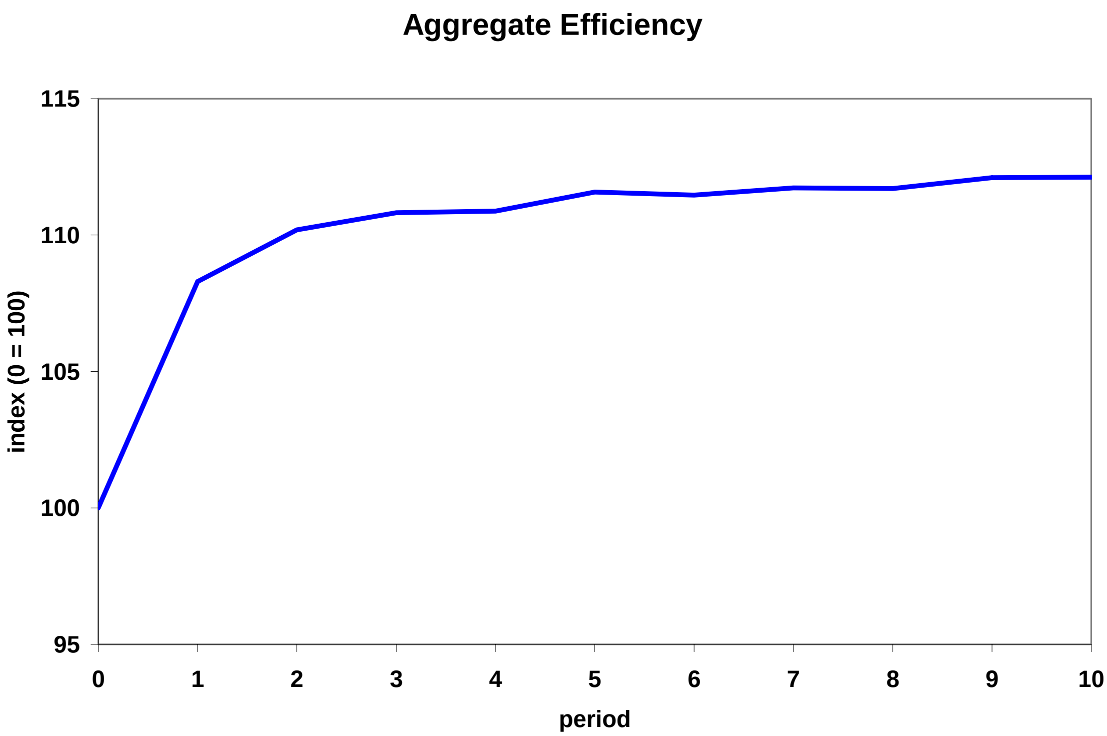

Aggregate Efficiency
115
110
105
100
95
index (0 = 100)
0
1
2
3
4
5
6
7
8
9
10
period

FIGURE 4

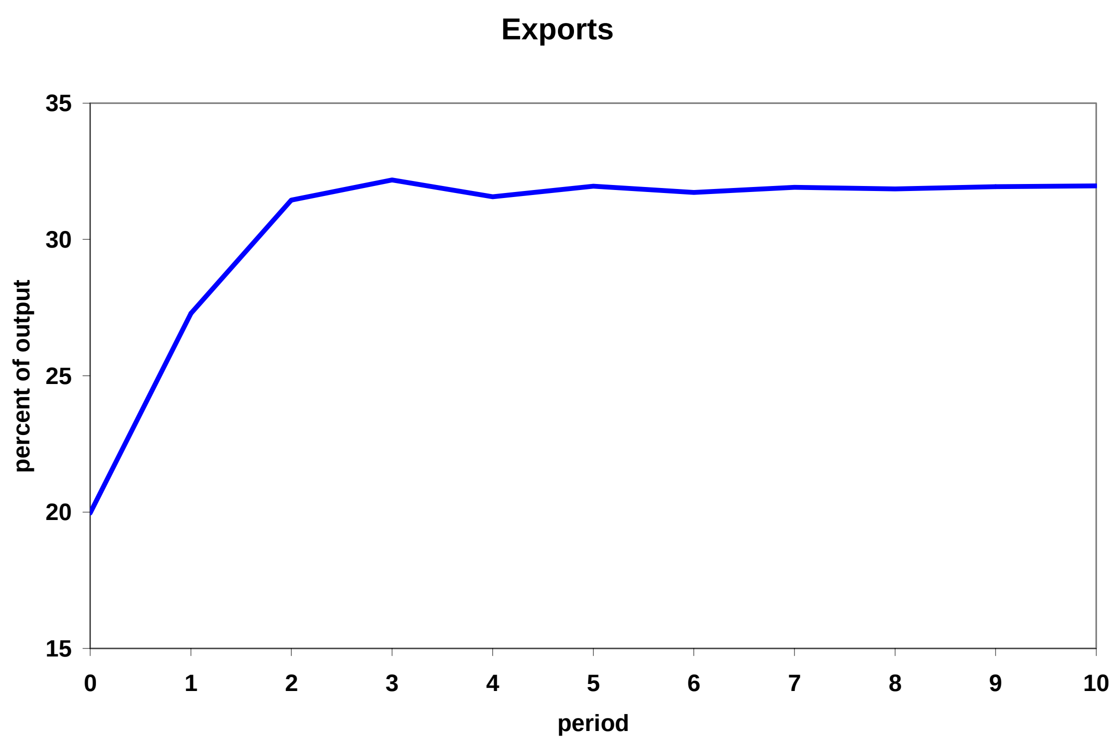
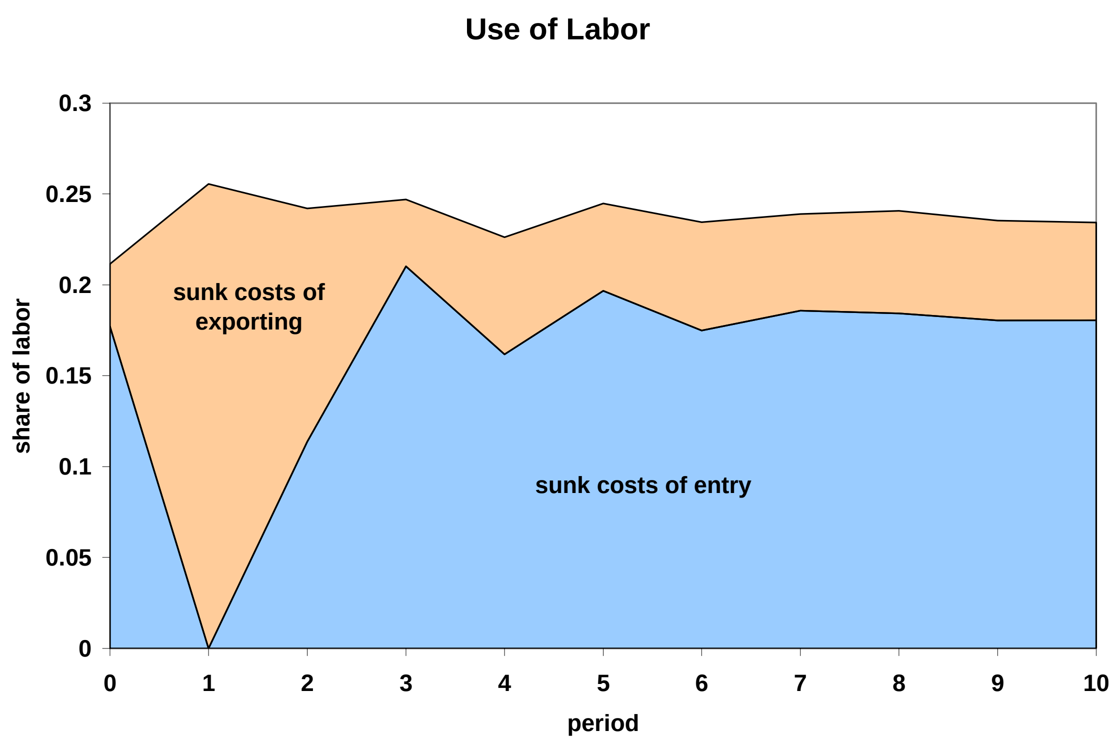
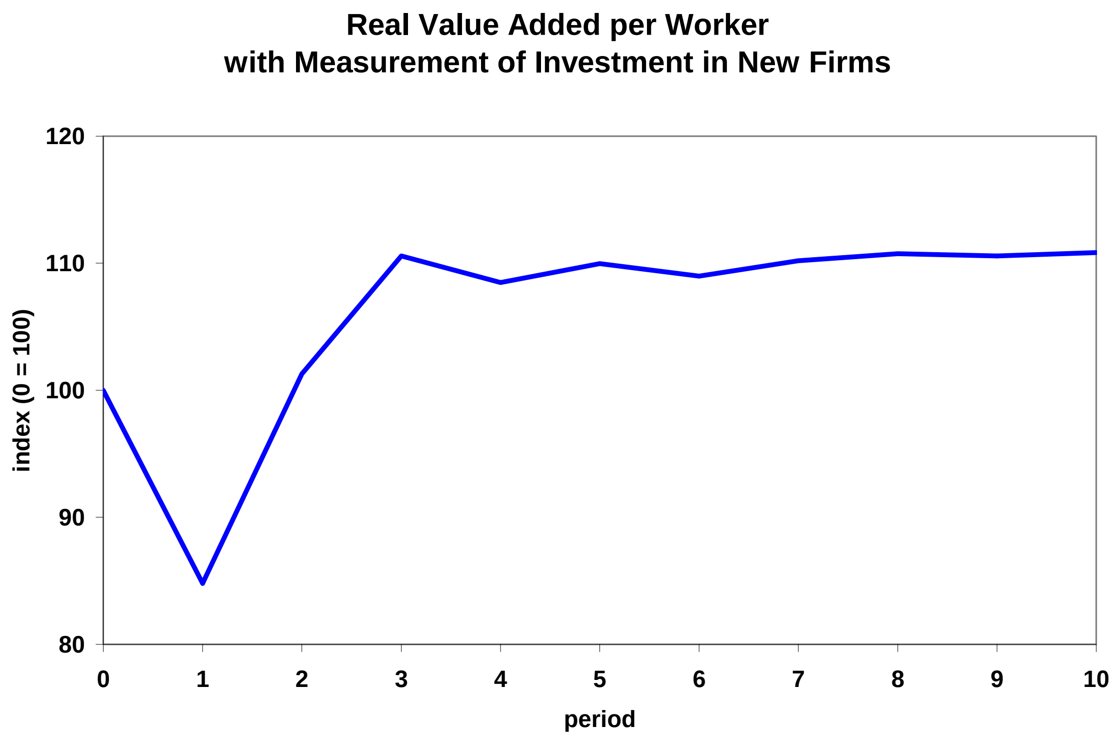

Exports
35
30
25
20
15
percent of output
0
1
2
3
4
5
6
7
8
9
10
period

FIGURE 5



Use of Labor
0.3
0.25
0.2
0.15
0.1
0.05
0
share of labor
sunk costs of exporting
sunk costs of entry
0
1
2
3
4
5
6
7
8
9
10
period

FIGURE 6


Real Value Added per Worker
with Measurement of Investment in New Firms
index (0 = 100)
120
110
100
90
80
0
1
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