Bigger is Better: Market Size, Demand Elasticity and Technology Adoption*

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Abstract

This paper's hypothesis is that larger markets facilitate technological innovation by raising the price elasticity of demand for a firm's product. Larger markets, either on account of a larger domestic population or more open trade, raise the price elasticity of demand by increasing competition between different goods. The higher elasticity has two implications. First, it implies a larger increase in revenues following the price reduction associated with the introduction of a more productive technology. Second, it implies larger firms in equilibrium. Both effects allow firms to more easily cover the costs of R&D. We illustrate this mechanism in a model with both process and product innovation and present evidence in support of our theory.

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1 Introduction

Two observations motivate this paper. First, bigger markets are associated with faster growth, catch-up and early development (Kremer, 1993; Sachs and Warner, 1995; Alesina et al 2000; McGratten and Prescott, 2007), and second, bigger markets are associated with more elastic demand (Tybout, 2003; Barron et al., 2003; Campbell and Hopenhayn, 2005). This paper argues that both phenomena are causally related. More specifically, it argues that bigger markets increase the price elasticity of demand for goods and services, and the more elastic demand facilitates technological change.

Bigger markets have higher elasticity because competition is stronger. The greater demand elasticity stimulates innovation through two channels. First, a firm that is faced with a more elastic demand experiences a larger percentage increase in its revenues when it lowers its price following the introduction of a more productive technology. Second, a more elastic demand leads to larger firms in equilibrium. Both channels allow a firm to more easily cover the costs of R&D.

Bigger in our theory is not a simple matter of population size. Rather, as the empirical evidence suggests, it is an issue of market integration, which depends not only on the number of people living in an area, but also on the extent to which goods and individuals are able to move in and out of the area. The positive effect of market size on growth and development may therefore have to do with population density (Chenery and Syrquin, 1975; Kremer, 1993), trade openness (Sachs and Warner, 1995; Alcalá and Ciccone, 2005), or the geography of market access (Redding and Venables, 2004). Likewise, the positive elasticity effect shows up both in larger geographical markets (Campbell and Hopenhayn, 2005) and more liberalized markets (Tybout, 2003).

Theories that predict a positive relation between market size and economic performance abound in the literature. In an important subset of these theories, bigger markets generate more ideas, and provide more consumers to buy those ideas (Romer, 1987; Aghion and Howitt, 1990; Grossman and Helpman, 1991). In another subset, the big push argument has emphasized externalities, in the form of demand linkages (Murphy, Shleifer and Vishny, 1989) or input-output chains (Ciccone, 2002). Yet another subset focuses on the effect of trade liberalization on innovation (Herrendorf and Teixeira, 2005). With the notable exception of Holmes and Schmitz (1995, 2001), this literature has not analyzed the elasticity channel.

The elasticity channel has largely been ignored because the literature has almost exclusively employed Dixit-Stiglitz (1977) preferences. With Dixit-Stiglitz, the price elasticity of demand, as well as the mark-up and the firm size, does not change with market size. In other words, the elasticity channel has been absent from the literature by construction.

To introduce the elasticity channel, we use Lancaster's (1979) preferences where each household has an ideal variety, identified by his location on a unit circle. As shown by Helpman and Krugman (1985) and Hummels and Lugovskyy (2005), this preference construct has the property that the price elasticity of demand for each variety is an increasing function of the market size. The key feature is that the product space is finite. When the population expands, and more varieties are added, the product space becomes more crowded. As a result, neighboring varieties become more substitutable, the demand elasticity increases, competition toughens, and markups fall. This same procompetitive effect is present when trade is liberalized. In that case, competition between existing varieties increases, and likewise, markups drop. To recoup their fixed cost, firm size must then increase.

Whereas Helpman and Krugman (1985) and Hummels and Lugovskyy (2005) show how bigger markets affect elasticity, markups, firm size and the number of varieties, we show how these same elements affect the technology choice of firms. We examine the choice of firms to upgrade their technology by paying an R&D/innovation cost. We show that firms are more likely to switch to a lower marginal cost production process when markets are bigger. As discussed before, the higher elasticity leads to two effects. A given price drop, in the wake of technology adoption, has a larger effect on revenues and profits if the elasticity is larger. Moreover, the higher elasticity makes competition tougher, so that firms need to become larger to continue to break even. Both effects are a consequence of the elasticity channel, and both lead to a positive scale effect in process innovation.

It is important to point out that we obtain a positive scale effect despite allowing for both process and product innovation. In a large class of endogenous growth models, such as Aghion and Howitt (1990) and Grossman and Helpman (1991), bigger markets lead to more process innovation, but only when the number of goods is exogenously given. Indeed, as shown by Young (1998), once one allows for product innovation, this scale effect disappears.[1] This does not happen in our model though: the scale effect in process innovation survives even when the number of goods is endogenously determined. Not surprisingly, the difference in results is a consequence of the presence or absence of an elasticity channel. If demand elasticity is constant, as in Dixit-Stiglitz, scale no longer matters; a given price drop has a constant effect on revenues, and firm size is constant, so that larger markets do not make it easier to bear the costs of innovation. Thus, an important contribution of this paper is to show that the elasticity channel may lead to a scale effect, where the existing literature claims that such an effect is absent.

With our structure, not only is the scale effect preserved, but the elasticity and technology effects of a larger market via trade liberalization and via population growth are the same. This is in contrast to Holmes and Schmitz (2001), who show that only trade liberalization, and not market size per se, affects elasticity and technological change. This contradicts the empirical evidence, which suggest that trade liberalization and population increase have similar effects, both in terms of elasticity and growth performance. Moreover, this dichotomy makes little theoretical sense: when trade costs go to zero, increasing the population size and liberalizing trade should be equivalent, a well-known principle in the trade literature on monopolistic competition (Krugman, 1979).

The dichotomy in Holmes and Schmitz (2001) has, once again, to do with the use of Dixit-Stiglitz preferences. In principle, their setup should not be able to generate an elasticity effect. However, unlike standard models of monopolistic competition, they

[1] Something similar happens in Atkeson and Burstein (2007) in the context of trade liberalization. In their model more open trade has no effect on innovation.

assume an asymmetry between domestic and foreign firms, whereby domestic firms can affect the manufacturing price index, but foreign firms cannot. This asymmetry explains why trade liberalization stimulates technology adoption but greater population does not. Eliminating this asymmetry would bring us back to the standard Dixit-Stiglitz result though: there would be no elasticity effect, and neither trade liberalization nor an increase in the domestic population would lead to more innovation.

Our paper is part of a burgeoning trade literature arguing that the Lancaster construct is more consistent with the empirical facts than the Dixit-Stiglitz construct. In addition to the aforementioned correlation between trade liberalization and markups (Tybout, 2003), there is the evidence that an increase in market size is associated with a less-than-proportional increase in the number of firms, so that larger markets have larger firms (Hummels and Klenow, 2005; Hummels and Lugovskyy, 2005). Although Lancaster preferences have not been used as extensively, it is worth recalling that the seminal work of Helpman and Krugman (1985) on trade and monopolistic competition analyzed both Dixit-Stiglitz and Lancaster. However, since they found that both types of preferences gave identical results for the issues they studied, the subsequent literature has almost single-mindedly adopted the Dixit-Stiglitz setup because of its analytical simplicity. As we argue in this paper, the difference between Lancaster and Dixit-Stiglitz is not only empirically relevant, it is also theoretically important: whereas Dixit-Stiglitz does not lead to a scale effect in process innovation, Lancaster does.

Lancaster preferences, while sufficient, are not necessary for generating our result. The only essential element is to adopt a preference structure whereby market size has a positive effect on the demand elasticity. The quasi-linear utility function with a quadratic sub-utility introduced by Ottaviano, Tabuchi and Thisse (2004) has this same feature. An example of its use is Melitz and Ottaviano (2005) who examine how larger markets increase the cutoff level of exogenous productivity levels, leading the least productive firms to exit. Although we could have easily used this preference structure, we did not for the primary reason that the demand for each differentiated good in the Ottaviano, Tabuchi, and Thisse (2004) construct is non-homothetic.[2]

The rest of the paper is organized as follows. Section 2 describes the open economy model and defines the symmetric equilibria. Section 3 explores the relation between market size and technological innovation. It does so first in a word with prohibitive trade costs, and studies how an increase in domestic population affects firms' technology choices. It then proceeds to analyze the same question as trade costs between two identically populated countries decline. Section 4 returns to the importance of the elasticity channel for our results. We modify the model so as to shut down the elasticity channel and show that firms' decisions to innovate no longer depend on market size. Section 5 concludes the paper.

2 The Model Economy

We extend Lancaster's (1979) model of trade in ideal varieties in the simplest manner possible in order to illustrate how larger markets facilitate innovation by increasing the price elasticity of demand for goods in the economy. There is both product innovation and process innovation in the model. The model consists of a single period with two identical countries. Each country has a business sector and a household sector. The business sector produces a set of differentiated goods by one of two increasing returns to scale technologies, each of which uses labor as its only input. The household sector supplies labor to the business sector and uses this income to buy a single variety of the differentiated good. Households are heterogenous in that each has one variety of the good he prefers over all others. In contrast to households, goods can be moved across countries, although at some cost. The model is described in detail in what follows.

2.1 Household Sector

In each country there is a continuum of measure L of households uniformly distributed along the unit circle. Each household is endowed with one unit of time that he supplies

[2] We conducted numerical experiments using the Ottaviano, Tabucchi and Thisse (2004) construct, and found the same qualitative results concerning the effect of larger markets on technology adoption.

inelastically to the business sector. Each household has one variety of the good which he prefers above all others. A household's ideal variety corresponds to his location on the unit circle. The farther away a particular variety, v, lies from a household's ideal variety, $\tilde{v}$, the lower the utility derived from a unit of consumption of variety v. Let $d_{v\tilde{v}}$ denote the shortest arc distance between variety v and the household's ideal variety $\tilde{v}$. Following Hummels and Lugovskyy (2005), the utility a type $\tilde{v}$ household derives from consuming c_v units of variety v is

$$u(c_v) = \frac{c_v}{1 + d_{v\tilde{v}}^{\beta}} \tag{1}$$

where $1 + d_{v\tilde{v}}^{\beta}$ is Lancaster's compensation function, i.e., the quantity of variety v that gives the household the same utility as one unit of its ideal variety $\tilde{v}$. The parameter β, where $\beta > 0$, determines how fast a household's utility diminishes with the distance from its ideal variety.

2.2 Business Sector

The business sector in each country produces a set of differentiated goods. Goods can be traded internationally, but at a cost. Trade costs are of the iceberg type. To deliver one unit of a given variety overseas requires a shipment of $\tau \geq 1$ units.

There are two increasing returns to scale technologies for producing each differentiated good. Labor is the only input into each technology. The increasing returns is the result of the existence of a fixed labor input requirement to production. We denote the fixed labor cost of technology $s = 1, 2$ by κ_s.[3] The existence of this fixed cost implies that the business sector in each country is monopolistically competitive. For each technology, the marginal product of labor is constant. We denote this constant marginal product of labor associated with technology $s = 1, 2$ by A_s. Let Q_v be the quantity of output of variety v produced by a firm using technology s and let L_v denote the units of labor it employs. Then,

$$Q_v = A_s[L_v - \kappa_s] \tag{2}$$

[3]We assume a fixed cost rather than a sunk cost because it ensures zero profits in equilibrium. The distinction is not critical for the results we wish to establish, however. We think of the higher fixed cost of technology 2 to be associated not only with operating the technology but also with developing it.

We assume that technology 2 is superior to technology 1 in the sense that $A_2 > A_1$. To make the technology choice interesting, we assume that $\kappa_2 > \kappa_1$. There are no other differences between the technologies. Thus, in deciding which technology to operate, a firm trades off between the higher marginal product of labor associated with technology 2 and the lower fixed cost associated with technology 1.[4]

2.3 Utility Maximization

Individual Demand

Let V denote the set of varieties produced in the world. The utility function (1) implies that each household buys only one differentiated good. In particular, a household will buy the variety v that minimizes the cost of a quantity equivalent to one unit of its ideal variety $\tilde{v}$, so that

$$v' = \operatorname{argmin}[p_v(1 + d_{v\tilde{v}}^{\beta})|v \in V]$$

He will spend his entire income on this good. Let w^i denote the wage of a household residing in country $i = H, F$.[5] Then, a household in country $i = H, F$ that consumes variety v' does so in a quantity given by

$$c_{v'}^i = w^i / p_{v'}^i \tag{3}$$

where $p_{v'}^i$ is the price of variety v' in country i.

Aggregate Demand

Having derived an individual household's demand, we next determine aggregate demand for a given variety. Aggregate demand for a given variety is the sum of the individual demands of households in the Home country and the Foreign country. For this purpose,

[4]The higher fixed cost of technology 2 is the simplest way to generate this tradeoff. Any other cost associated with adopting technology 2 would suffice. In earlier versions of the paper, we assumed two alternative costs: a pricing constraint that arose from a competitive fringe that could produce λA_2 units of an innovating industry's variety with one unit of labor ($\lambda < 1$), and a costly buy-out of specialized factor suppliers to technology 1.

[5]Free entry into the industrial sector ensures that firms there make zero profits in equilibrium. Thus, the only income of a household is its labor income.

we introduce some additional notation. In particular, we use a double superscript so as to distinguish between the production location and the consumption location. In this convention, the first superscript refers to the production location, and the second superscript refers to the consumption location. Thus, Q^{HF} would denote the quantity of some variety produced in the Home country and sold in the Foreign country.

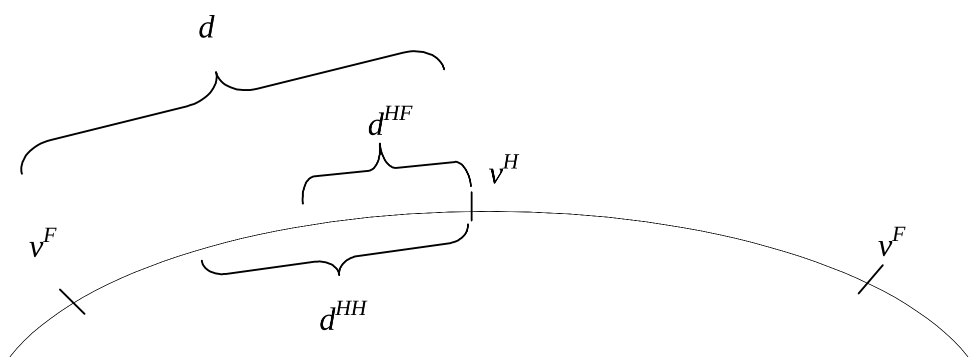

Figure 1: Varieties and Consumers on the Unit Circle

As we will study only symmetric Nash Equilibria, we derive the aggregate demand for a given variety assuming that all varieties produced in the world are equally spaced along the unit circle. In this case, aggregate demand for a given variety only depends on the locations and the prices of its closest neighbors to its right and to its left.[6]

For reasons of space, we only derive the aggregate demand for a Home produced variety v^H. (The demand for a Foreign produced variety can be derived by analogy.) For this purpose it is useful to consider the segment of the unit circle depicted in Figure 1. In a symmetric setup, the varieties that are located nearest to Home produced variety v^H are produced by Foreign firms. Moreover, these varieties are both located distance d from the Home produced variety v^H. For this reason, we do not need to distinguish

[6] If all other varieties are symmetric, the prices and locations of varieties other than the closest neighbors to the right and to the left do not matter. If the other varieties were asymmetric, we would have to constrain $\beta > 1$ to be able to make the same statement.

between these two foreign competitors, and denote either one of them by v^F.

To derive the aggregate demand for variety v^H, we first determine the total demand for this good by households in the Home country. Denote the price of variety v^H in the Home market by p^{HH}, and the price of variety v^F in the Home market by p^{FH}. The Home household who is indifferent between buying varieties v^H and v^F is the one located at distance d^{HH} from v^H, where:

$$p^{FH}[1 + (d - d^{HH})^\beta] = p^{HH}[1 + (d^{HH})^\beta] \tag{4}$$

Given this indifference condition applies to both households to the right and to the left of v^H, a share $2d^{HH}$ of Home households consume variety v^H given the locations and prices of the nearest competitors of variety $v^{H\prime}$ to its right and to its left. As Home households are uniformly distributed along the unit circle, it follows that Home households will buy C^{HH} units of variety v^H where

$$C^{HH} = \frac{2d^{HH} w^H L}{p^{HH}} \tag{5}$$

Next we determine the Foreign household demand for variety v^H. The derivation is slightly different on account that trade is costly. Recall that for one unit of a good to arrive in the overseas market, $\tau \geq 1$ units must be shipped. In the Foreign market the price of v^H is denoted by p^{HF}, whereas the price of v^F is denoted by p^{FF}. The Foreign household who is indifferent between buying v^H and v^F is located at distance d^{HF} from v^H, where d^{HF} satisfies

$$p^{FF}[1 + (d - d^{HF})^\beta] = p^{HF}[1 + (d^{HF})^\beta] \tag{6}$$

Again, since this indifference condition applies to households both to the right and to the left of v^H, a share $2d^{HF}$ of Foreign households consume variety v^H. Demand of that same variety in the Foreign market is, thus,

$$C^{HF} = \frac{2d^{HF} w^F L}{p^{HF}} \tag{7}$$

Because of iceberg costs, the total production of variety v^H need not equal world consumption. More specifically, if trade costs are nonprohibitive, the total quantity of the good produced by a firm will be less than world consumption of that good. Let Q^{HH} denote the production destined to the Home market by the firm producing v^{H}, and let Q^{HF} denote output destined to the foreign market. Then,

$$Q^{HH} = C^{HH} = \frac{2d^{HH}w^{H}L}{p^{HH}} \tag{8}$$

and

$$Q^{HF} = \tau C^{HF} = \frac{2d^{HF}w^{F}L}{p^{HF}} \tag{9}$$

The demand expressions for a Foreign produced variety can be derived by analogy.

2.4 Profit Maximization

Having derived world demand for each variety and established the relation between production and consumption, we next proceed to characterize the profit maximizing choices of a firm producing a particular variety in a given country. We do this in two steps. First, we characterize the profit maximizing prices and quantities of a firm, assuming that it uses a particular technology $s = 1, 2$. Next, we characterize the optimal choice of technology of such a firm.

Prices and Quantities

The fixed cost κ_s associated with each technology implies that each variety, regardless of the technology used, will be produced by a single firm. In maximizing its profits, a firm takes the choices of other firms in both countries as given. Firms behave non-cooperatively. In what follows, we present the problem facing a Home firm. (Expressions for Foreign firms can be derived by analogy.)

A Home firm chooses p^{HH}, p^{HF}, Q^{HH} and Q^{HF} to maximize profits, namely,

$$p^{HH}Q^{HH} + p^{HF}\frac{Q^{HF}}{\tau} - w^{H}(\kappa_s + (Q^{HH} + Q^{HF})/A_s) \tag{10}$$

subject to demand in the Home market, (8), and the Foreign market, (9). The wage paid to a worker, w^{H}, is taken as given by each firm in the Home country. As in the standard monopoly problem, the profit maximizing price in each market is a markup over the marginal unit cost w^H/A_s, namely

$$p^{HH} = \frac{w^H}{A_s}\frac{\varepsilon^{HH}}{\varepsilon^{HH}-1} \tag{11}$$

$$\frac{p^{HF}}{\tau} = \frac{w^H}{A_s}\frac{\varepsilon^{HF}}{\varepsilon^{HF}-1} \tag{12}$$

where ε^{HH} and $\varepsilon^{HF}$are the price elasticities of demand for variety v in the Home country and in the Foreign country, namely,[7]

$$\varepsilon^{HH} = -\frac{\partial Q^{HH}}{\partial p^{HH}}\frac{p^{HH}}{Q^{HH}}$$

$$\varepsilon^{HF} = -\frac{\partial Q^{HF}}{\partial p^{HF}}\frac{p^{HF}}{Q^{HF}}$$

Recall that d^{HH} is the shortest arc distance between the firm and the indifferent Home customer, and d is the shortest arc distance between the firm and its nearest competitors. Given the variety's demand (8), it is easy to show that

$$1-\varepsilon^{HH} = \frac{\partial d^{HH}}{\partial p^{HH}}\frac{p^{HH}}{d^{HH}} \tag{13}$$

Differentiating both sides of equation (4) with respect to p^{HH} yields

$$\varepsilon^{HH} = 1 + \frac{[1+(d^{HH})^{\beta}p^{HH}}{[p^{HH}\beta(d^{HH})^{\beta-1}+p^{FH}\beta(d-d^{HH})^{\beta-1}]d^{HH}} \tag{14}$$

By analogy, the elasticity faced by a Home firm in the Foreign market can be shown to be

$$\varepsilon^{HF} = 1 + \frac{[1+(d^{HF})^{\beta}]p^{HF}}{[p^{HF}\beta(d^{HF})^{\beta-1}+p^{FF}\beta(d-d^{HF})^{\beta-1})d^{HF}} \tag{15}$$

Technologies

The technology a firm chooses is the one that generates the highest profits. In deciding which technology to use, a firm takes the locations, prices, quantities, and technologies of all other firms in the world as given.

[7] Unlike with Dixit-Stiglitz preferences, elasticities may differ across markets, so that p^{HF} need not be equal to τp^{HH}.

2.5 Symmetric Equilibrium

As is standard in these models, we exclusively focus on symmetric Nash equilibria. In addition to utility maximization, profit maximization, and market clearing, a necessary condition for a symmetric equilibrium is zero profits. This is a consequence of free entry and exit. The zero profit condition of a firm located in the Home country is

$$p^{HH}Q^{HH} + p^{HF}\frac{Q^{HF}}{\tau} - w^{H}[\kappa_s + (Q^{HH} + Q^{HF})/A_s] = 0 \tag{16}$$

The zero profit condition for both the Home firms and Foreign firms determines the number of varieties of goods that are produced in the world economy.

There are two types of symmetric equilibria. In both types, $x^{ij} = x^{ji}$ and $x^{ii} = x^{jj}$ for any variable x, with $i, j = H, F$. In the first type all firms use the less productive technology. In the second type all firms use the more productive technology. We refer to the first type as the *Symmetric Equilibrium with No Adoption (SENA)*, and to the second type as the *Symmetric Equilibrium with Adoption (SEA)*.

For both equilibria, there are ten necessary and sufficient conditions. Nine of these conditions are straightforward, and are essentially the same for both equilibria, except for the technology used. The last is a no-deviation condition to ensure that firms using a given technology do not switch to the other technology. For a *Symmetric Equilibrium with No Adoption (SENA)*, it must be the case that no individual firm would find it optimal to use technology 2, given the prices and locations of all other firms in the world and given that all other firms use technology 1. For a *Symmetric Equilibrium with Adoption (SEA)*, it must be the case that no single firm would find it optimal to use technology 1, given the prices and locations of all other firms in the world and given that all other firms use technology 2.

We start by stating the nine conditions shared by the two equilibria. These are:

Definition 1 *1. Profit maximization by firm from country i in market i:*

$$p^{ii} = \frac{w^{i}}{A_s}\frac{\varepsilon^{ii}}{\varepsilon^{ii} - 1}$$

2. *Profit maximization by firm from country i in market j:*

$$\frac{p^{ij}}{\tau} = \frac{w^i}{A_s}\frac{\varepsilon^{ij}}{\varepsilon^{ij}-1}$$

3. *Elasticity faced by firm from country i in market i:*

$$\varepsilon^{ii} = 1 + \frac{[1+(d^{ii})^{\beta}]p^{ii}}{[p^{ii}\beta(d^{ii})^{\beta-1} + p^{ij}\beta(d-d^{ii})^{\beta-1}]d^{ii}}$$

4. *Elasticity faced by firm from country i in market j:*

$$\varepsilon^{ij} = 1 + \frac{[1+(d^{ij})^{\beta}]p^{ij}}{[p^{ij}\beta(d^{ij})^{\beta-1} + p^{ii}\beta(d-d^{ij})^{\beta-1}]d^{ij}}$$

5. *Indifferent household from country i for product from country i:*

$$p^{ij}[1+(d-d^{ii})^{\beta}] = p^{ii}[1+(d^{ii})^{\beta}]$$

6. *Indifferent household from country j for product from country i:*

$$p^{ii}[1+(d-d^{ij})^{\beta}] = p^{ij}[1+(d^{ij})^{\beta}]$$

7. *Production by firm from country i for market i:*

$$Q^{ii} = \frac{2d^{ii}w^iL}{p^{ii}}$$

8. *Production by firm from country i for market j:*

$$Q^{ij} = \frac{2\tau d^{ij}w^jL}{p^{ij}}$$

9. *Zero profit condition for firm from country i:*

$$p^{ii}Q^{ii} + p^{ij}\frac{Q^{ij}}{\tau} - w^i[\kappa_s + (Q^{ii}+Q^{ij})/A_s] = 0$$

2.6 Symmetric Equilibrium with No Adoption

We are now ready to define the *Symmetric Equilibrium with No Adoption (SENA).*

Definition 2 *The Symmetric Equilibrium with No Adoption (SENA) is vector of elements* (p^{ii*}, ε^{ii*},p^{ij*}, ε^{ij*}, d^*, d^{ii*}, d^{ij*}, Q^{ii*},Q^{ij*}), *where* $i, j \in \{H, F\}$ *and* $i \neq j$, *that satisfies Conditions 1-9 in Definition 1, in addition to the no deviation condition*

10. *No firm in country i finds it profitable to adopt the more productive technology. In particular,* $\pi_i' < 0$, *where* π_i' *equals*

$$
\begin{aligned}
\arg\max \quad & p^{ii}Q^{ii} + \frac{p^{ij}}{\tau}Q^{ij} - w^{i*}(\kappa_2 + [Q^{ii} + Q^{ij}]/A_2)) \\
s.t. \quad & Q^{ii} = \frac{2d^{ii}w^{i*}L}{p^{ii}} \\
& Q^{ij} = \frac{2\tau d^{ij}w^{i*}L}{p^{ij}} \\
& p^{ij*}[1 + (d^* - d^{ii})^\beta] = p^{ii}[1 + (d^{ii})^\beta] \\
& p^{jj*}[1 + (d^* - d^{ij})^\beta] = p^{ij}[1 + (d^{ij})^\beta]
\end{aligned}
$$

2.7 Symmetric Equilibrium with Adoption

Likewise the *Symmetric Equilibrium with Adoption (SEA)* can be defined as follows.

Definition 3 *The Symmetric Equilibrium with Adoption (SEA) is a vector of elements* ($\widehat{p^{ii}}$, $\widehat{\varepsilon^{ii}}$, $\widehat{p^{ij}}$, $\widehat{\varepsilon^{ij}}$, $\widehat{d}$, $\widehat{d^{ii}}$, $\widehat{d^{ij}}$, $\widehat{Q^{ij}}$, $\widehat{Q^{ij}}$), *where* $i, j \in \{H, F\}$ *and* $i \neq j$, *that satisfies Conditions 1-9 in Definition 1, in addition to the no deviation condition*

10. *No firm in country i finds it profitable to adopt the more productive technology. In particular,* $\pi_i'' < 0$, *where* π_i'' *equals*

$$
\begin{aligned}
\arg\max \quad & p^{ii}Q^{ii} + \frac{p^{ij}}{\tau}Q^{ij} - \widehat{w^i}[\kappa_2 + (Q^{ii} + Q^{ij})/A_2] \\
s.t. \quad & Q^{ii} = \frac{2d^{ii}\widehat{w^i}L}{p^{ii}} \\
& Q^{ij} = \frac{2\tau d^{ij}\widehat{w^i}L)}{p^{ij}} \\
& \widehat{p^{ij}}[1 + (\widehat{d} - d^{ii})^\beta] = p^{ii}[1 + (d^{ii})^\beta] \\
& \widehat{p^{ij}}[1 + (\widehat{d} - d^{ij})^\beta] = p^{ij}[1 + (d^{ij})^\beta]
\end{aligned}
$$

3 Market Size

Having defined the symmetric equilibria, we now analyze the issue of how their existence depends on the size of the market. In particular, for a given measure of households in each country, and a given trade cost, we determine whether each type of equilibrium exists, and if so, characterize its properties. As a larger domestic population in Holmes and Schmitz (2001) does not have the same effect on innovation as the introduction of free trade, we first study the case where trade costs are infinite and vary the size of the domestic population. This allows us to analyze the effect of larger markets due to a larger domestic population. We follow this by a set of experiments where we keep the domestic population of both countries fixed, but change the trade costs.

Our methodology is as follows. For a given parametrization, including a measure of households and a trade cost, we first compute the prices and allocations that satisfy all but the no-deviation condition of the *Symmetric Equilibrium with No Adoption (SENA)* and the prices and allocations that satisfy all but the no-deviation condition of the *Symmetric Equilibrium with Adoption (SEA)*. We then check if the no-deviation condition for each symmetric equilibrium is satisfied for the respective candidate set of prices and allocations. If it is, then we conclude that such a symmetric equilibrium exists.

Table 1: Parameter values

$\beta = 0.55$	
$\kappa_1 = .4$	$\kappa_2 = 1.0$
$A_1 = 1/0.05$	$A_2 = 1/0.045$

Table 1 lists the values of the preferences and technology parameters used in the two sets of experiments. The preference parameter, β, associated with Lancaster's compensation function has been assigned a value based on empirical evidence. Its value was set to fit the empirical regularity of a positive relation between trade liberalization and elasticity (Tybout, 2003).[8] Consistent with the theoretical model, the technology

[8]When there are positive trade costs, the elasticity faced by a firm in Home and Foreign is different. Whether a drop in trade costs — which amounts to an increase in market size — leads to an increase in

parameters have been chosen such that technology 2 has a higher marginal productivity and a higher fixed cost than technology 1.

3.1 Population Size

The first experiment interprets market size as population size. We set $\tau = \infty$, so that each country is closed, and vary the size of the population. Table 2 reports the results of these numerical experiments for the Home country. For small population sizes, the only symmetric equilibrium is the one without adoption. For intermediate population sizes, both symmetric equilibria — without and with adoption — exist. For big population sizes, this multiplicity disappears, and only the symmetric equilibrium with adoption remains. We can therefore conclude that greater market size facilitates the adoption of the more productive technology.

Table 2: Market Size: Population

Population	Number Firms	Elasticity	Indirect Utility	Deviation	Equilibrium
Symmetric Equilibrium with No Adoption (SENA)					
50	15.7	8.0	15.9	-4.6	SENA
75	20.9	9.0	16.3	-3.6	SENA
100	25.5	9.8	16.7	-2.8	SENA
125	29.7	10.5	16.9	-2.1	SENA
Multiple Equilibria (SENA or SEA)					
150	33.7	11.1	17.1	-1.4	SENA
	17.8	8.4	17.9	-0.5	SEA
175	37.5	11.7	17.2	-0.8	SENA
	19.9	8.8	18.1	-1.0	SEA
200	41.1	12.2	17.3	-0.3	SENA
	21.8	9.2	18.2	-1.5	SEA
Symmetric Equilibrium with Adoption (SEA)					
225	23.7	9.5	18.4	-1.9	SEA
250	25.5	9.8	18.5	-2.2	SEA
275	27.2	10.1	18.6	-2.5	SEA
300	28.9	10.4	18.7	-2.8	SEA

elasticity depends on the value of β.

The positive relation between population size and elasticity is what eventually gives individual firms the incentive to switch to the more productive technology. As explained before, a higher demand elasticity leads to larger firms, and implies a greater effect on revenue (and profits) for a given drop in prices. Both effects facilitate technology adoption. To see this, consider the equilibrium properties of only *SENA* in Table 2. As the population size increases from 50 to 200, the number of firms (and varieties) goes up from 15.7 to 41.1. The variety space becomes more crowded, neighboring varieties become more substitutable, and the elasticity of demand increases from 8.0 to 12.2. The effect of this increase in elasticity is to make the losses of deviating from the *SENA* smaller. As can be seen in column 5, the losses from deviating go from -4.6 when the population is 50 to -0.3 when the population is 200. Eventually, when the population reaches some level 200 and 250, the profits for a firm switching to the more productive technology become positive, and *SENA* ceases to exist.

Although not the main focus of this paper, it is still useful to understand why multiple equilibria may arise. Table 2 shows that when comparing *SENA* and *SEA* for a same population size, both the number of firms and the elasticity is lower under *SEA*. Because of the bigger fixed cost associated with the more productive technology, firms have to be larger under *SEA* in order to break even, thus implying ferwer firms and lower elasticity. This may lead to multiple equilibria. If no one else adopts, firm size is too small for an individual firm to have an incentive to switch to the more productive technology. However, if everyone else adopts, firm size becomes large enough for an individual firm to bear the higher fixed cost of the better technology.

As far as indirect utility is concerned, market size has three positive effects. First, larger markets lead to larger average firm size, implying more efficient production, higher real wages and higher utility. Second, ignoring technology adoption, larger markets increase the number of varieties, so that the average household is located closer to its ideal variety, thus further increasing its utility. Third, technology adoption in larger economies reinforces the positive effects on efficiency and utility.

The first two effects of market size on indirect utility are present in standard

Lancaster-type models (Helpman and Krugman, 1985); the third effect is specific to our model. This can be seen in Figure 2. The indirect utility has been computed for the 'average' household, i.e., the household located at a distance $d/4$ from its ideal variety. The lower curve represents the indirect uility under *SENA* and the upper curve represents the indirect utility under *SEA*. Both curves are upward sloping: this reflects the first two effects of standard Lancaster models. But the *SEA* curve is above the *SENA* curve: the difference represents the contribution of innovation to the indirect utility.

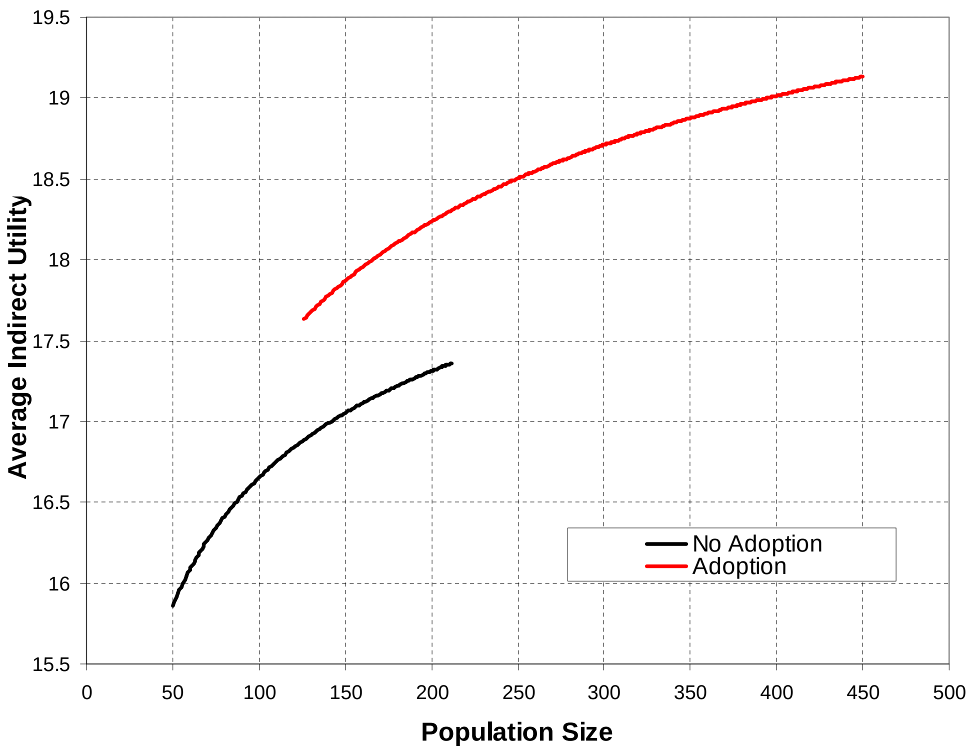

Figure 2: Population Size, Technology Adoption, and Indirect Utility

3.2 Trade Liberalization

The second set of experiments interprets market size as trade liberalization. We use the same technology and preference parameter values as before, but now fix the Home and Foreign populations equal to $L = 125$. We start off with a trade cost $\tau = 1.25$, and then decrease it so as to analyze how trade liberalization affects the incentive to adopt the more productive technology. The results are reported in Table 3.

Table 3: Market Size: Trade Liberalization

Trade Costs	Number Firms	Elasticity	Indirect Utility	Deviation	Equilibrium
Symmetric Equilibrium with No Adoption (SENA)					
1.250	95.2	10.6	16.2	-5.3	SENA
1.225	85.9	11.3	16.4	-4.7	SENA
1.200	77.4	11.9	16.6	-4.0	SENA
1.175	70.0	12.4	16.7	-3.3	SENA
Multiple Equilibria (SENA or SEA)					
1.150	63.7	12.7	16.8	-2.4	SENA
	29.7	9.7	17.8	-0.2	SEA
1.125	58.6	12.9	16.9	-1.6	SENA
	28.4	9.7	17.9	-0.7	SEA
1.100	54.6	13.0	17.0	-0.9	SENA
	27.4	9.8	18.0	-1.2	SEA
1.075	51.6	13.1	17.1	-0.2	SENA
	26.6	9.8	18.1	-1.6	SEA
Symmetric Equilibrium with Adoption (SEA)					
1.050	26.0	9.8	18.2	-1.9	SEA
1.025	25.6	9.8	18.4	-2.1	SEA
1.000	25.486	9.8	18.5	-2.2	SEA

For trade costs τ between 1.25 and 1.075, the only symmetric equilibrium that exists is *SENA*, the one with no innovation. Once τ drops below 1.175, both symmetric equilibria, *SENA* and *SEA*, exist. If trade costs drop further to below 1.075, the multiplicity disappears, and the unique symmetric equilibrium becomes *SEA*. Market size through trade liberalization has become big enough to ensure technology adoption.

Although once again the elasticity channel is at work, its origin is different. Whereas in the case of an increase in population the variety space becomes more crowded, in the case of lowering trade costs the competition between neighboring Home and Foreign varieties becomes stronger. This latter effect implies that as trade is liberalized, the tougher competition eliminates some varieties. Population growth therefore leads to more varieties, whereas trade liberalization leads to less varieties. However, in both cases the two effects underlying the positive relation between market size and innovation are the same: the greater elasticity makes firms larger and leads to a bigger effect on profits when the marginal cost drops.

Note that when $\tau = 1$ and there is complete free trade, the results in Table 3 for a population size of 125 in each country are equivalent to those in Table 2 for a closed economy with population 250. In that sense, there is no dichotomy between population size and trade liberalization. In contrast to Holmes and Schmitz (1995, 2001), a one-country closed economy with population size L is equivalent to a two-country open economy with zero trade costs and population size $L/2$ in each country.

4 The Elasticity Channel

The hypothesis of this paper is that bigger markers facilitate innovation by making the demand for goods and services more price elastic. There is no other mechanism at hand in generating this scale effect in our theory. To convince the reader that there are no other channels at work, we modify the model so as to shut down the elasticity channel and then determine how technology choice varies with market size. Without the elasticity channel there is no relation between market size and technology adoption.

Before describing the modification, it is instructive to show algebraically how a larger market raises the price elasticity of demand for a given variety. In an open economy without transportation costs, symmetry implies that $p^{HH} = p^{HF} = p$ and $d^{HH} = d^{HF} = d/2$. Therefore, the elasticity expressions (14) and (15) both simplify to

$$\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{d})^{\beta} + \frac{1}{2\beta} \tag{17}$$

By plugging in the price expressions (11) and (12) into the zero profit condition (16), we get that the total production of a firm is $\kappa_s A_s/(\varepsilon - 1)$. With a total population of L, this implies that the total number of firms is $n = L/(\kappa\varepsilon)$, where $n = 1/d$. Substituting into (17) gives

$$\varepsilon = 1 + \frac{1}{2\beta}(\frac{2L}{\kappa_s \varepsilon})^{\beta} + \frac{1}{2\beta} \tag{18}$$

To see the effect of population size on elasticity, we totally differentiate (18) and get

$$\frac{d\varepsilon}{dL} = \frac{(2/\kappa_s)^{\beta}\beta L^{\beta-1}}{2\beta(\beta+1)\varepsilon^{\beta} - (2\beta+1)\beta\varepsilon^{\beta-1}} \tag{19}$$

Since $\varepsilon > 1$, this expression is positive, so that an increase in L leads to a greater elasticity of demand.

Larger markets increase the elasticity of demand, but do they work to affect technological adoption through some other channel? For the purpose of answering this question, we modify the preference structure of the model. It would be straightforward to show this in a Dixit-Stiglitz type modification, with their constant demand elasticity feature, that there would be no positive scale effect in process innovation. However, to make the comparison as sharp as possible, we modify the Lancaster construct so that the elasticity result shown above is voided.

Remember that the elasticity effect in Lancaster is due to the variety space becoming more crowded as more firms enter the market and the distance between neighboring varieties becomes smaller. We now analyze what would happen if neighboring varieties were not to become more substitutable as their number increased. To adapt our model, we distinguish between two concepts, the *objective* distance and the *subjective* distance. The *objective* distance is the one defined before; it refers to the actual distance on the unit circle. The *subjective* distance refers to the one perceived by households. Until now, these two concepts were identical. However, we now assume that as the number of varieties increases, so that the objective distance between neighboring varieties decreases, the subjective distance does not change. One way of interpreting this asymmetry is that as more firms enter the market, they become better at differentiating their products, thus leaving the subjective distance between neighboring varieties unchanged. To avoid confusion between the two concepts, we use a "~" whenever we refer to the subjective distance.

We define a benchmark population for which the objective and subjective distances are the same. Denote by $\bar{n}$ the number of firms corresponding to the benchmark population. This allows us to define the subjective distance between two varieties v and v' as

$$\tilde{d}_{vv'} = \frac{n}{\bar{n}} d_{vv'} \tag{20}$$

This definition implies that if, compared to the benchmark case, the number of varieties doubles, then the subjective distance will be double the objective distance.

The essential feature is that the subjective distance between neighboring varieties, $\tilde{d}$, is now independent of the number of firms, n. To see this, notice that the objective distance between neighboring varieties, d, is equal to $1/n$. Substituting this into (20) implies that $\tilde{d} = (n/\bar{n})(1/n)$, so that $\tilde{d} = 1/\bar{n}$. In other words, the subjective distance between neighboring varieties is constant, and equal to the objective distance corresponding to the benchmark population. This implies that as more firms enter the market, neighboring varieties no longer become more substitutable, so that the elasticity channel is shut off.

To solve this variation of our model, the only change we need to introduce is to make the utility of consuming variety v dependent on the subjective distance between v and the household's ideal variety $\tilde{v}$. Therefore, (1) now becomes

$$u(c_v) = \frac{c_v}{1 + (\tilde{d}_{v\tilde{v}})^{\beta}} \tag{21}$$

The rest of the model is the same as before.

Table 4: Shutting Down the Elasticity Channel

Population	Number Firms	Elasticity	Indirect Utility	Deviation	Equilibrium
Symmetric Equilibrium with No Adoption (SENA)					
50	15.7	8.0	15.9	-4.6	SENA
75	23.6	8.0	15.9	-4.6	SENA
100	31.4	8.0	15.9	-4.6	SENA
125	39.2	8.0	15.9	-4.6	SENA
150	47.1	8.0	15.9	-4.6	SENA
175	55.0	8.0	15.9	-4.6	SENA
200	62.8	8.0	15.9	-4.6	SENA
225	70.7	8.0	15.9	-4.6	SENA
250	78.5	8.0	15.9	-4.6	SENA

We now re-do the first set of numerical experiments where we shut down international trade using the preference and parameter values listed in Table 1. For the benchmark where the objective and subjective distances are the same we use $N = 50$. The number of varieties produced for the benchmark, which is the number of varieties produced in the *SENA* listed in Table 2 is 15.7. Thus, for the modified model, $\bar{n} = 15.7$. With these benchmark values in hand, we can determine how the existence of the *SEA* depends on the size of the market.

The results are summarized in Table 4. The major finding is that for every population only the *SENA* exists. Firms never find it optimal to use technology 2. By the selection of the benchmark, the results listed in Tables 4 and 2 are the same for $L = 50$. However, in Table 4 we observe that the elasticity remains unchanged as the market size increases. These constant elasticities imply constant markups, and through the zero profit condition, imply constant firm sizes. As a result, the number of firms now increases proportionately to the size of the population. The elasticity channel has thus been shut down; firms no longer increase in size, and a given price drop has a constant effect on revenues. This explains why the incentive to innovate and adopt the better technology has become independent of population size. Indeed, as can be seen in the second-to-last column in Table 4, the profits generated by an individual firm that deviates and switches to the more productive technology are constant and negative. No matter how much the population grows, the only symmetric equilibrium is the one with no adoption.[9]

5 Concluding Remarks

The hypothesis of this paper is that larger markets facilitate technological change by increasing the price elasticity of demand for goods and services. If the elasticity of demand is high, the drop in the price following the adoption of a more productive technology translates into a substantial increase in revenues and profits. In addition, greater elasticity leads to larger firms in equilibrium. This makes it easier for firms to upgrade their technology. While technological change in the paper was modeled as the application of existing ideas, the implications of our model extend to the creation in ideas. Moreover, the results do not depend on the nature of the costs associated with the more productive technology. Our results would not change were we to assume that the more productive

[9] In this particular numerical exercise there are no multiple equilibria, so that *SEA* does not exist.

technology required a research expenditure, or a buy-out of factor suppliers to the existing technology, or some combination.

For these reasons, we think our theory is relevant for both rich and poor countries, both from a contemporary and historical perspective. We think our theory might shed light on why the Industrial Revolution started in England in the 18$^{\text{th}}$ century and not earlier. Mokyr (2005) argues that what sets the pre-Industrial Revolution period apart from the Industrial Revolution is not a lack of technological creativity, but rather overwhelming resistance to innovation. Our theory offers a potential explanation as to why this resistance dramatically decreased in England when it did: prior to the 18$^{\text{th}}$ century, population and transportation were insufficient in England to give people there the incentive to want to adopt new ideas. We also think that our theory may shed some light on economic reforms implemented by many poor countries in the last twenty years have failed to bring about large increases in living standards. According to our theory, economic reforms may not matter much if an economy's market is too small either on account of low population, trade barriers or inadequate infrastructure.

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