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

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Abstract

This paper's hypothesis is that larger markets facilitate the adoption of more productive technology by raising the price elasticity of demand for a firm's product. A larger market, either because of population or free trade, thus implies a larger increase in revenues following the price reduction associated with the introduction of a more productive technology. As a result, technology adoption is more profitable, and the earnings of factor suppliers are less likely to be adversely affected. Firms operating in larger markets, therefore, have a greater incentive to adopt more productive technologies, and their factor suppliers have a smaller incentive to resist these adoptions. This is the case even when there is no fixed resource cost to adoption. We demonstrate this mechanism numerically and provide empirical support for this theory.

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1 Introduction

Why is it that poor countries often fail to adopt more productive, readily-available technologies? In these societies, either firms never attempt to introduce more productive technologies, or when they do, their efforts are successfully resisted by special interest groups, often comprised of factor suppliers. This paper examines the role of population size and free trade in determining whether firms will attempt to adopt more productive technologies and whether their factor suppliers will resist these attempts.

Its hypothesis is that a larger market facilitates the adoption of more productive technology by raising the price elasticity of demand for a firm's product. A larger market, either because of population or free trade, thus implies a larger increase in revenues following the price reduction associated with the introduction of a more productive technology. As a result, adoptions are more profitable, and the earnings of factor suppliers are less likely to be adversely affected. Firms operating in larger markets, therefore, have a greater incentive to adopt more productive technologies, and their factor suppliers have a smaller incentive to resist these adoptions.[1] This is the case even when there is no fixed resource cost to adoption.

We demonstrate this mechanism in a version of Lancaster's (1979) model of trade in ideal varieties. As shown by Helpman and Krugman (1985) and Hummels and Lugovskyy (2005), this model has the property that the absolute value of the elasticity of demand for a product is an increasing function of the population size. Because the product space is finite and each good is assigned a unique "address" in this space, the substitutability between varieties increases as the number of goods produced increases. As larger economies produce more varieties, the price elasticity of demand for each industry's product is higher and competition is tougher.

Whereas these authors examine how population size and free trade affect the price elasticity of demand and the number of varieties produced by an economy, we examine how these same elements affect the incentives of firms to adopt more productive technologies,

[1]Throughout the paper, we follow the literature and refer to an economy with a larger population as a larger market.

and the incentives of their workers to resist those adoptions. We extend the model so that each variety can be produced by either of two technologies that differ in the amount of labor input required per unit of output. There is no fixed resource cost needed to adopt the more productive technology. In this sense, the more productive technology is freely available.

Adoption is not costless, however. We separately consider two costs incurred by an adopting industry. The first cost is associated with a loss of monopoly power over the less productive technology, and takes the form of a price ceiling. Once a firm upgrades its technology, any household in the economy can start producing that firm's variety using the less productive technology. As a result, an adopting firm cannot set too high a price for its variety. Otherwise, it would elicit entry by this competitive fringe. The second cost is associated with skill obsolescence, and takes the form of lower wages accrued by an adopting firm's workers. Only a subset of households in the economy has the necessary skills to operate the less productive technology, but every household is equally adept in operating the more productive technology. As a result, households who specialize in the less productive technology experience a wage drop if their firm adopts. For each of these two adoption costs, we determine whether there exists a symmetric equilibrium with adoption or without adoption; we characterize the corresponding prices and allocations; and we examine how the equilibrium properties of the model change with the economy's population.

Each of these costs has a strong theoretical basis. Parente and Prescott (1999) and Herrendorf and Teixeira (2005), for example, make use of the first type of cost, whereas Krusell and Rios-Rull (1996) and Bellettini and Ottaviano (2005) make use of the second type of cost. Whereas all of these papers study resistance to technological change, they do not explicitly consider how market size affects the incentives to block more productive technologies. In the case of the second cost, there is a strong empirical basis as well. Skill obsolescence following technological change is a well-documented phenomenon.

In the case where adoption is associated with the loss of monopoly power over the less productive technology, the pricing constraint leads to negative profits for an adopting firm when the market size is small and the elasticity of demand is low. In small enough markets, firms therefore stick to the less productive technology. However, if the market size is large, and the elasticity of demand is high, the pricing constraint no longer leads to negative profits, so that firms switch to the more productive technology.

The higher elasticity of demand in larger markets is key to understanding these results. The elasticity of demand operates through two channels. First, as the elasticity of demand increases, firms face tougher competition, and the mark-up they charge decreases. The smaller mark-up implies a smaller price drop imposed by the pricing constraint. Second, as the elasticity of demand increases, a given percentage price drop leads to a greater percentage increase in total revenue. Put differently, in more competitive markets a reduction in price translates into a bigger gain in market share.

In the case where adoption is associated with skill obsolescence, workers resist their firm's attempts to adopt the more productive technology. Such resistance did not arise with the first type of cost, as the interests of a firm and its workers were always aligned. In contrast, with skill obsolescence, adoption is optimal for the firm, but not for its workers, who stand to lose in the form of lower wages. To break resistance, a firm must be able to compensate its workers for any loss in earnings, using the profits generated by the adoption. Again, population size and free trade matter. When market size is small and the elasticity of demand is low, firms are unable to sufficiently compensate their workers for the lower wages, so that no adoption occurs; when market size is large and the elasticity of demand is high, the profits of an adopting firm are sufficiently large to fully compensate its workers for the drop in their wages, so that adoption occurs. Once again, the positive relation between market size and demand elasticity is crucial. The price drop, following technology adoption, has a greater effect on revenues and profits, the larger the elasticity of demand.

The use of Lancaster ideal variety preferences, while important, is not essential for generating these results. What matters, instead, is the positive relation between market size and the elasticity of demand. Our results would not change had we used the quasi-linear utility function with a quadratic sub-utility studied by Ottaviano, Tabuchi and Thisse (2002). The Dixit-Stiglitz (1977) construct is, however, insufficient for our purpose. In that framework the substitutability between varieties does not increase with the numbers of varieties in the market, so that there is no elasticity effect associated with a larger market size. Certainly, with a Dixit-Stiglitz preferences it is still possible to generate positive welfare and productivity effects from an increase in market size. Typically, this is accomplished by introducing a fixed cost to innovation, thus implying a scale effect.[2] In our model, there is no such fixed resource cost to adopting. Indeed, we purposely abstract from this resource cost as to not confuse the scale effect with the price elasticity effect.

There is one exception in this literature using the Dixit-Stiglitz construct that examines resistance to costless technology adoption: Holmes and Schmitz (2001). Their paper is closely related to ours. Like us, they show that a larger market size lowers the resistance to process innovations through a change in the elasticity of demand for an industry's product. However, there is a key difference: in their paper only trade-related and not population-related increases in market size work to increase the price elasticity of demand. In other words, increases in market size due to population growth do not lower resistance to technology adoption. The dichotomy in their model is an artifact of the Dixit-Stiglitz structure, as well as a number of special assumptions, such as that every domestically produced industrial good has close substitutes abroad but not domestically. In contrast, in our work trade liberalization and increases in population operate in exactly the same way.

Another related paper is Melitz and Ottaviano (2005), who generate an elasticity effect using the Ottaviano, Tabuchi and Thisse (2004) preferences. As in our work, their model does not predict any dichotomy between free trade and population. They do not, however, study technology adoption or resistance. In their model, firms choose to enter a market and then realize their productivity and marginal production costs. Ex-post, low productivity firms choose not to produce. Trade and country size raise average

[2]For example, Rodrigues (2005) obtains this result by assuming increasing returns to specialization. There are also numerous examples within the endogenous growth literature, with a so-called scale-effect property, including Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).

productivity by raising the cut-off level whereby a firm would choose to exit the industry.[3] Though we also emphasize the relation between market size and elasticity, we focus on a model where technology adoption is a decision, rather than the outcome of entry and exit and random assignment.[4] In that respect our model is more similar to Yeaple (2005). However, Yeaple (2005) uses Dixit-Stiglitz preferences, so that the elasticity of demand is not part of the discussion.

In emphasizing the importance of market size for technological change, we do not mean to imply that there are no other factors that prevent firms in poor countries from attempting to introduce more productive technologies developed by the rich countries. Geography, capital market imperfections, and illiterate populations may make it unprofitable for firms in poor countries to adopt certain technologies. Nor do we mean to suggest that there is no other mechanism by which free trade or population size works to lower resistance to technology adoption. Holmes and Schmitz (1995), for example, put forth a "sink or swim" hypothesis whereby any firm that uses a less productive technology will be unable to compete in the absence of trade barriers.[5]

The paper is organized as follows. Section 2 presents empirical support for the mechanism we propose by which population size and free trade work to facilitate the adoption of better technology. Section 3 lays out the basic structure of the Lancastarian ideal variety model. Sections 4 analyzes the equilibrium properties of the model when the adoption cost takes the form of a pricing constraint. Section 5 does the same when the adoption cost takes the form of lower wages. Section 6 concludes the paper.

[3] This is essentially the same mechanism as in Syverson (2004). However, his model does not imply an elasticity effect. Instead, it follows Salop (1979) and assumes consumers have an inelastic demand for a single unit of the economy's output.

[4] A further difference with Melitz and Ottaviano (2005) is the absence of firm heterogeneity in our model. We abstract from firm heterogeneity, not because it is unimportant, but because it is not central to the mechanism we emphasize.

[5] However, there are countless examples of technologies not being adopted that cannot be attributed to any of the aforementioned factors, and are thus in need of an alternative explanation. Some excellent contemporary examples can be found in Bailey and Gersbach (1995). An excellent historical example is found in Clark (1987).

2 Empirical Support

The purpose of this section is to provide empirical support for our theory. The empirical support makes use of aggregate-level, industry-level and firm-level data. Before presenting this evidence, however, it is instructive to recall those features and predictions of our model that in their entirety set it apart from the rest of the literature. Our work has vertical innovations and resistance to those innovations; our work is based on a mechanism whereby larger market size works to increase the price elasticity of demand; and our work predicts that both population size and free trade work to eliminate resistance.

Process Innovations and Resistance

Resistance to the introduction of superior technologies is a well-documented phenomenon that dates back to the start of civilization.[6] In the middle ages, the guilds were notorious for blocking the introduction of new production processes, new goods, and work practices. A number of tactics have been employed by groups to block the introduction of new technologies. Laws and regulations have and continue to be a popular means by which groups resist the adoption of better technology. Strikes have also proven to be a useful method by which worker groups block the adoption of new technologies. At times, groups have even resorted to sabotage and violence. Although this last tactic was more common in the past, it is still employed today as is evident in a case documented by Fox and Heller (2000) for a large paper mill in Karelia, Russia.

The fact that we observe resistance to innovation implies that fixed and sunk costs cannot have been prohibitively large in these instances. Otherwise, the plant owners or their managers would never have attempted to introduce these new technologies in the first place. Indeed, there are many well-documented instances where an innovation required no new expenditure, and yet was not adopted. Wolcott (1994), for example, documents the huge number of strikes by Indian textile workers at the turn of the twentieth century to stop plans by management to reorganize and reassign tasks in the textile mills. More

[6] Mokyr (1990) provides a comprehensive history of resistance to technological change in the world.

recently, Klebnikov and Waxler (1996) analyze the case of the Volga Paper Company in Russia, in which huge crates placed in a remote part of the factory containing $100 million in new Austrian-made equipment were found unopened in an inspection by Western investors.

Elasticity of Demand and Market Size

A number of theories, many of which belong to the new trade literature, argue that trade liberalization increases the price elasticity of demand of goods. An extensive body of empirical work examining whether this relation holds has grown out of this literature. Most of this work uses mark-ups, rather than price elasticities, as these theories imply that mark-ups are a decreasing function of the elasticity of demand, and as estimates of price elasticities are generally unavailable. Using plant-level data, these studies find ample evidence that trade liberalization is associated with lower mark-ups.[7]

While these papers support our theory, they are deficient in that they do not examine the impact of larger markets, per se, on the price elasticity of demand, and neither do they directly measure the impact on the price elasticity. Two relevant papers in that respect are Campbell and Hopenhayn (2005) and Barron, Umbeck, and Waddell (2003). Campbell and Hopenhayn (2005) provide evidence of the retail industry across 225 U.S. cities, consistent with larger markets having lower mark-ups and higher demand elasticities. Barron, Umbeck, and Waddell (2002) actually estimate price elasticities of demand for gasoline using price and quantity data from individual gas stations in Southern California. They find that the larger Los Angeles market is characterized by lower prices and more elastic demand than the smaller San Diego market.

Population Size, Free Trade and Resistance

Here we provide aggregate and industry-level evidence consistent with population and free trade having a positive effect on economic performance. At the aggregate level, a large

[7] See Tybout (2003) for an excellent survey of the theoretical and empirical work in this area, as well as the methods used to infer mark-ups.

empirical literature concludes that greater openness is associated with faster growth in per capita output or GDP (see, e.g., Sachs and Warner, 1995, Edwards, 1998, Wacziarg and Welch, 2003, and Alcalá and Ciccone, 2004).[8] Of particular interest is Alesina, Spaloare and Wacziarg (2000), who find that a small population lowers a country's economic performance only if the country is closed. In other words, trade provides a way to compensate for small domestic size. At the industry-level, Syverson (2004) finds that average productivity in the ready-mix concrete sector is higher in larger geographical markets in the United States.

This evidence does not rule out other theories by which larger populations or free trade facilitate the adoption of more productive technologies, such as the "sink or swim" hypothesis modeled by Holmes and Schmitz (1995). Ideally, to separate our theory from others, we require an event study of an industry that prior to trade liberalization resists the adoption of a better technology despite being the world productivity leader, and after trade liberalization adopts the technology. Such event studies are not well-documented.

One such case pertains to the woolen industry in the West of England in the late 18$^{\text{th}}$ century and the attempts of mill owners to mechanize the cleaning and mixing of wool fibers through the use of scribbling machines. At that time the woolen industry in the West of England was the envy of the world. Despite this, these attempts were successfully resisted by the mill workers through means of violence and intimidation, as they feared the introduction of scribbling machines would lead to lower wages and employment. According to Randall (1991), this resistance, which began in 1791, ended four years later in the wake of a trade boom. Greater trade removed workers' fears as they found they could not meet the demand for English woolen cloth using the inferior technology for cleaning and mixing the wool fibers.

Another relevant case that also pertains to the English textile industry in the same period involves the Luddite riots. No example of worker resistance is perhaps more famous than the Luddites, who from 1811 to 1817 terrorized mill owners by smashing looms and frames and burning down factories. It is generally recognized that the depressed state of

[8] See, nonetheless, the critical review of Rodrik and Rodríguez (2000).

the English textile industry that resulted from the Napoleonic Wars, and more specifically from the Prince Regent's Order in Council that prohibited trade with allies of France, was a major factor for this resistance. With the removal of this order in 1817 the Luddites stopped their resistance and violence.[9]

3 The Model Economy

We demonstrate the mechanism at hand using Lancaster's ideal variety model. The model is static and consists of three sectors: an agricultural sector, an industrial sector, and a household sector. The agricultural sector is competitive and produces a homogeneous good, which serves as the economy's numéraire, using labor as its only input. The industrial sector also uses labor as its only input, but in contrast is monopolistically competitive and produces a differentiated good. The different varieties of the industrial good are located on the unit circle. There is a single technology to produce the agricultural good, but two available technologies to produce each differentiated industrial good. Those two technologies differ in their marginal labor inputs. The household sector is populated by a continuum of households of measure N, distributed uniformly around the unit circle. A household's location on the unit circle corresponds to the variety of the differentiated good that it most strongly prefers. Households supply labor to firms in the economy and use the income generated by this activity to buy the agricultural good and the differentiated goods.

In this section, we describe each of these three sectors in detail. In addition, we analyze the utility maximization problem of households, and the profit maximization problem of agricultural firms. We postpone the analysis of the profit maximization problem of industrial firms as it depends on the way we introduce the cost of adopting the more productive technology.

[9] According to Binfield (2004), wage concessions, some abatement in food prices, and military force also contributed to the end of the Luddite riots.

3.1 Household Sector

Preferences

A household's utility depends on its consumption of the agricultural good and the differentiated industrial goods. We denote a household's consumption of the agricultural good by c_a and its consumption of the differentiated good v by c_v, where $v \in V$. Households are uniformly distributed along the unit circle. Each household's location on the unit circle corresponds to its ideal variety of the industrial good. The farther away a particular variety of the industrial good, 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 of a type $\tilde{v}$ household is

$$U = c_a^{1-\alpha}[u(c_v|v \in V)]^{\alpha} \tag{1}$$

where

$$u(c_v|v \in V) = \max_{v \in V}[\frac{c_v}{1 + d_{v,\tilde{v}}^{\beta}}] \tag{2}$$

In equation (1), α is a parameter that determines the expenditure share of the household between the agricultural good and the differentiated goods. In equation (2), the term $1 + d_{v,\tilde{v}}^{\beta}$ 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 determines how fast a household's utility diminishes with the distance from its ideal variety. As is standard with Lancaster preferences, we restrict β to be greater than 1. This implies that compensation rises at an increasing rate as the household moves away from its ideal variety.

Endowments

Each household is endowed with one unit of time. Households may differ with respect to how they can use their time endowment, namely, whether they can work in the agricultural sector, the industrial sector with the less productive technology, or the industrial sector with the more productive technology. For the purposes at hand, it is sufficient to distinguish between two types of households, Type-1 and Type-2. To ensure that a symmetric equilibrium exists, we assume that Type-1 households, of which there is measure N_1 in the economy, and Type-2 households, of which there is measure $N_2 = N - N_1$, are each uniformly distributed along the unit circle. We postpone the complete specification of the time uses of each type until Sections 4 and 5, as they depend on how the adoption cost is modeled.

3.2 Agricultural Sector

There is a single technology to produce the agricultural good. It uses labor as its only input and exhibits constant returns to scale. Let Q_a denote the quantity of agricultural output and let L_a denote the labor input. Then

$$Q_a = \Omega_a L_a \tag{3}$$

where Ω_a is agricultural TFP.

3.3 Industrial Sector

Each differentiated good can be produced with either of two technologies. Labor is the only input to each technology. The two technologies differ in their marginal labor inputs. The marginal labor input for the first technology is ϕ_1, whereas it is ϕ_2 for the second technology. We assume that $\phi_1 > \phi_2$ so that the second technology is more productive. There is a fixed cost κ modeled in labor units associated with operating either technology. Let L_v denote the total labor input of a firm producing variety v, and let Q_v be the output of such a firm. Then, the output associated with using technology $i = 1, 2$ is

$$Q_v = \phi_i^{-1}[L_v - \kappa] \tag{4}$$

3.4 Household Utility Maximization

Individual Demand

Given that households may differ in the use of their time endowment, they may differ in their incomes. Let w_1 denote the wage earned by a household of Type 1 and w_2 the wage earned by a household of Type 2.[10] Cobb-Douglas preferences imply that each household spends fraction $1-\alpha$ of its income on the agricultural good, and the remaining fraction α on the differentiated goods. That is

$$c_a^i = (1-\alpha)w_i \quad \text{if } i = 1, 2 \tag{5}$$

$$\int_{v\in V} p_v c_v^i = \alpha w_i \quad \text{if } i = 1, 2 \tag{6}$$

The sub-utility function given by equation (2) implies that each household buys only one differentiated good. As such, the quantity of the variety v' purchased by a household satisfies

$$c_{v'}^i = \alpha w_i / p_{v'} \tag{7}$$

The variety v' that a household located at $\tilde{v}$ on the unit circle buys is the one that maximizes

$$\frac{\alpha w_i}{p_v(1+d_{v\tilde{v}}^{\beta})}$$

It follows immediately that this household buys the variety v that minimizes $p_v(1+d_{v\tilde{v}}^{\beta})$, so that

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

Aggregate Demand

Having derived an individual household's demand, we can determine aggregate household demand for a given variety. The following argument is based on Figure 1. The aggregate demand facing a firm producing variety v depends on the location on the unit circle of its nearest competitor to its left, s, and to its right, z, as well as on the prices charged by those firms, p_s and p_z. If the price of variety v is p_v, then the household on the unit circle who is just indifferent between buying variety v and variety s is identified by location u, which satisfies

$$p_s(1+d_{su}^{\beta}) = p_v(1+d_{uv}^{\beta})$$

[10] 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.

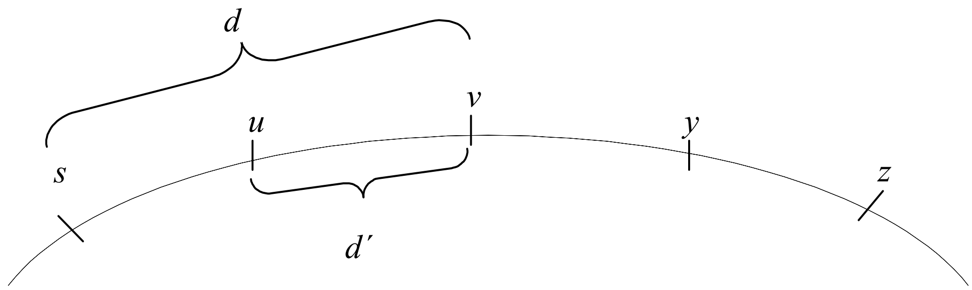

Figure 1: Varieties, competitors and consumers on the unit circle

Similarly, the household on the unit circle who is just indifferent between buying variety v and variety z is identified by location y, which satisfies

$$p_z(1 + d_{yz}^{\beta}) = p_v(1 + d_{yv}^{\beta})$$

Given these prices and locations, it follows that the customer base of industry v is the compact set of households with ideal variety located between u and y. More specifically, the share of customers served by industry v equals the shortest arc distance between variety v and u, d_{uv}, plus the shortest arc distance between variety v and y, d_{yv}.

As household preferences imply that each household spends fraction α of its total income on a single variety and as each household type is uniformly distributed along the unit circle, it follows that total demand for firm v's product is

$$Q_v = \frac{(d_{uv} + d_{yv})\alpha[w_1 N_1 + w_2 N_2]}{p_v}$$

In a symmetric equilibrium, $d_{uv} = d_{yv}$ and $d_{sv} = d_{zv}$. In that case, denote the distance between firm v and the indifferent household by d', the distance between firm v and its nearest competitor to the right (and to the left) by d, and the price charged by these competitors by p. Then, firm v's total demand is

$$Q_v = \frac{2d'\alpha[w_1 N_1 + w_2 N_2]}{p_v} \tag{8}$$

and the condition that determines the indifferent customer can be re-written as

$$p[1 + (d - d')^{\beta}] = p_v[1 + d'^{\beta}] \tag{9}$$

3.5 Agricultural firm equilibrium conditions

The agricultural sector is competitive. Let w_a denote the wage rate paid to a household working in the agricultural sector. The problem of an agricultural firm is to maximize profits, namely, $\Omega_a L_a - w_a L$, taking the wage rate as given. The first order necessary condition is

$$w_a = \Omega_a$$

4 Adoption Cost #1: Loss of Monopoly Control

In this section we study the equilibrium properties of the model when adoption entails a loss of monopoly control over the less productive technology. In particular, as long as an industrial firm uses the less productive technology to produce its variety, no one else in the economy can produce that firm's variety. However, if it opts for the more productive technology, any household is free to use the the less productive technology to produce the firm's variety, without incurring the fixed cost, κ. This risk of competitive entry imposes a cost on the adopting firm in the form of a pricing constraint.[11] This is the only cost incurred by an adopting industry; there is no firm-specific fixed investment needed to adopt the superior technology.

To understand the threat of competitive entry, it is important to specify the constraints on the use of the households' time endowment. Type-2 households are the only ones that can be employed by industrial firms, whereas Type-1 households are constrained to be laborers in the agricultural sector unless an industrial firm switches to the more productive technology. In that case, a Type-1 household is allowed to produce the firm's

[11] The assumption that a household can enter the industry without having to incur the fixed cost is made solely for analytical convenience. In particular, it allows us to avoid introducing additional strategic elements in the model. Qualitatively, none of the paper's main results would be altered if we were to assume that households using the less productive technology were subject to the fixed cost of production.

variety using the less productive technology as as a self-employed worker. A Type-2 household is similarly allowed to become a self-employed worker using the less productive technology. To deter competitive entry, an adopting firm will therefore have an incentive to charge a low enough price. This explains why the loss of monopoly control leads to a pricing constraint.

In what follows, we first characterize the relevant problem of industrial sector firms, and then describe the entire set of necessary conditions for a symmetric equilibrium where all industries fail to adopt the more productive technology and a symmetric equilibrium where all industries adopt the more productive technology. Next, through the use of computations we examine how the equilibrium properties of the model change as the population increases. In this way, we show that market size facilitates the adoption of the more productive technology by increasing the price elasticity of demand for each industry's product.

4.1 Profit Maximization of Industrial Firms

The existence of the fixed cost, κ, implies that a single firm will produce a given variety. Being a monopolist, a firm chooses its variety as well as its price, output, technology, and labor input to maximize its profits subject to the demand for its product. In doing so the firm takes the choices of other firms as given. Thus, industrial firms behave non-cooperatively. In case a firm uses the more productive technology, it faces the additional constraint that entry will occur by households using the less productive technology if it sets too high a price for its variety.

As is standard, we focus exclusively on symmetric Nash equilibria. In a symmetric equilibrium, all industrial firms are equally spaced along the unit circle, charge the same price, employ the same number of workers, and use the same technology. In this particular framework, there are two possible symmetric equilibria, one where all industrial firms use the less productive technology and another where they have all switched to the more productive technology.

The No Adoption Case

In the case a firm does not use the more productive technology, its problem is to choose p_v, Q_v, and L_v to maximize

$$p_v Q_v - w_x L_v$$

subject to the variety's demand (8) and the production technology (4) with $\phi_i = \phi_1$. The wage rate paid to an industrial worker, w_x, is taken as given by each industrial firm on account that labor is not specific to any one firm. As in the standard monopoly problem, the profit maximizing price is a mark-up over the marginal unit cost of production $w_x\phi_1$, namely

$$p_v = \frac{w_x \phi_1 \varepsilon}{\varepsilon - 1} \tag{10}$$

In the above equation, ε is the price elasticity of demand for variety v, namely,

$$\varepsilon = -\frac{\partial Q_v}{\partial p_v}\frac{p_v}{Q_v}$$

Recall that d' is the shortest arc distance between the firm and the indifferent customer and d is the shortest arc distance between the firm and its nearest competitor. Given the variety's demand (8) it is easy to show that

$$1 - \varepsilon = \frac{\partial d'}{\partial p_v}\frac{p_v}{d'} \tag{11}$$

Differentiating both sides of equation (9) with respect to p_v yields

$$\frac{\partial d'}{\partial p_v} = \frac{-(1 + d'^{\beta})}{p\beta(d - d')^{\beta - 1} + p_v \beta d'^{\beta - 1}}$$

Using this result together with equation (11) yields the following expression for the price elasticity of demand

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

In a symmetric equilibrium, $p_v = p$ and $d' = d/2$, so that

$$\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{d})^{\beta} + \frac{1}{2\beta} \tag{12}$$

The Adoption Case

In the case all firms use the more productive technology, profit maximization is subject to an additional constraint that amounts to a ceiling on the price a firm can charge. If a firm adopts the more productive technology, then any household can use its own labor to produce the same variety with the less productive technology, without having to incur the fixed cost. Type-1 households will do so if the income they could earn from producing variety v with the old technology, p_v/ϕ_1, is greater than the wage they could earn in the agricultural sector, w_a; Type-2 households will do the same if p_v/ϕ_1 is greater than w_x. This threat of competitive entry firms imposes an effective ceiling on the price the firm using the more productive technology can charge, namely, $p_v \leq \min\{w_a\phi_1, w_x\phi_1\}$.

As the maximization problem for a firm is the same except for this additional constraint, the first order necessary conditions are the same as in the no-adoption case, with the difference that

$$p_v = \min\{\min\{w_a\phi_1, w_x\phi_1\}, \frac{w_x\phi_2\varepsilon}{\varepsilon - 1}\}$$

4.2 Zero Industrial Profit Condition

The profits of each industrial firm are zero in equilibrium. This follows from the existence of the fixed cost, which is only incurred if a firm has positive production. Consequently, firms will either enter or exit the industrial sector until profits of all industries are driven to zero. The zero-profit condition effectively pins down the number of varieties produced in the economy. In a symmetric equilibrium the number of varieties is equal to the inverse of the arc distance between neighboring firms on the unit circle. Thus, if d is the distance between any two varieties, then the number of varieties in a symmetric equilibrium is d^{-1}.

Profits of a firm using technology ϕ_i can be written as $p_vQ_v - w_x(\kappa + Q_v\phi_i)$. In the symmetric equilibrium where no industry adopts the more productive technology, the zero-profit condition is

$$Q_v = \kappa\phi_1^{-1}(\varepsilon - 1)$$

This is derived by substituting the profit maximizing price (10) into the profit equation and setting profits to zero. In the symmetric equilibrium where all firms adopt the more productive technology this condition is

$$Q_v = \begin{cases} w_x\kappa/[\min\{w_a\phi_1, w_x\phi_1\} - w_x\phi_2] & \text{if } p_v = \min\{w_a\phi_1, w_x\phi_1\} \\ \kappa\phi_2^{-1}(\varepsilon - 1) & \text{if } p_v = w_x\phi_2\varepsilon/(\varepsilon - 1) \end{cases}$$

4.3 Symmetric Equilibrium with No Adoption

We are now ready to define a *Symmetric Equilibrium with No Adoption.*

Definition 1 *A Symmetric Equilibrium with No Adoption is a vector of prices and allocations* $(w_a^* = w_1, w_x^* = w_2, d^*, \varepsilon^*, L_v^*, L_a^*, Q_v^*, p^*, c_a^{1*}, c_a^{2*})$ *that satisfies*

1. $c_a^i = (1-\alpha)w_i \quad i = 1, 2$ *(utility maximization of type i household)*
2. $N_1 c_a^1 + N_2 c_a^2 = \Omega_a L_a$ *(agricultural market clears)*
3. $w_a = \Omega_a$ *(profit maximization agricultural firms)*
4. $L_v/d = N_2$ *(industrial labor market clears)*
5. $L_a = N_1$ *(agricultural labor market clears)*
6. $\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{d})^\beta + \frac{1}{2\beta}$ *(definition of elasticity)*
7. $p = \frac{w_x\phi_1\varepsilon}{\varepsilon-1}$ *(profit maximization of industrial firm)*
8. $Q_v = \kappa\phi_1^{-1}(\varepsilon - 1)$ *(zero profit condition)*
9. $Q_v = \frac{d\alpha[w_a N_1 + w_x N_2]}{p}$ *(demand for variety v)*
10. $Q_v = \phi_1^{-1}(L_v - \kappa)$ *(supply of variety v)*
11. *No firm finds it profitable to adopt the more productive technology. Namely,* $\hat{\pi} < 0$

where $\hat{\pi}$ *equals*

$$\begin{aligned} \arg \max_{d',\varepsilon,p_v,Q_v} \quad & \{p_v Q_v - w_x^*[Q_v\phi_2 + \kappa]\} \\ s.t. \quad & Q_v = \frac{2d'\alpha[w_a^* N_1 + w_x^* N_2]}{p_v} \\ & p_v^*[1 + (d^* - d')^\beta] = p_v[1 + d'^\beta] \\ & p_v \leq \min\{w_a^*\phi_1, w_x^*\phi_1\} \\ & \varepsilon = 1 + \frac{(1 + d'^\beta)p_v}{[p_v^*\beta(d^* - d')^{\beta-1} + p_v\beta d'^{\beta-1}]d'} \end{aligned}$$

The last condition in the above definition says that no firm should have an incentive to deviate and adopt the more productive technology. Otherwise, the prices and allocations would not be a Nash equilibrium. The constraints corresponding to the deviating firm's maximization problem in this last condition are derived as follows. A firm producing variety v that deviates will almost surely want to charge a price different from p^*. This, in turn, will affect its customer base. The household who is indifferent between buying from the deviating firm and its closest competitor is located at the distance from the deviating firm, d', that satisfies

$$p^*(1 + (d^* - d')^\beta) = p_v(1 + d'^\beta) \tag{13}$$

As d^* is the distance between two neighboring firms, then a share d' will buy from the deviating firm, and a share $d^* - d'$ will buy from its neighbor. By implicit differentiation,

$$\frac{\partial d'}{\partial p_v} = -\frac{1 + d'^\beta}{p^*\beta(d^* - d')^{\beta-1} + p_v\beta d'^{\beta-1}} \tag{14}$$

Given that each firm has two neighbors, the total customer share of the deviating firm is $2d'$. Thus, the demand for the deviating firm's goods is:

$$Q_v = \frac{2d'\alpha[w_a^* N_1 + w_x^* N_2]}{p_v} \tag{15}$$

Differentiating Q_v in (15) with respect to p_v, and using expression (14) yields the following expression for the deviating firm's elasticity:

$$\varepsilon_v = 1 + \frac{(1 + d'^\beta)p_v}{[p_v^*\beta(d^* - d')^{\beta-1} + p_v\beta d'^{\beta-1}]d'} \tag{16}$$

The pricing constraint $p_v \leq \min\{w_a^*\phi_1, w_x^*\phi_1\}$ is the other constraint in the no-deviating condition. It is surely critical. Absent this constraint, firms would *always* want to deviate, given there is no firm-specific investment required to adopt the more productive technology.

4.4 Symmetric Equilibrium with Adoption

By analogy, a *Symmetric Equilibrium with Adoption* can now be defined as:

Definition 2 *A Symmetric Equilibrium with Adoption is a vector of prices and allocations* $(w_a^* = w_1, w_x^* = w_2, d^*, \varepsilon^*, L_v^*, L_a^*, Q_v^*, p^*, c_a^{1*}, c_a^{2*})$ *that satisfies*

1. $c_a^i = (1-\alpha)w_i \quad i = 1, 2$ *(utility maximization of type i household)*

2. $N_1 c_a^1 + N_2 c_a^2 = \Omega_a L_a$ *(agricultural market clears)*

3. $w_a = \Omega_a$ *(profit maximization agricultural firms)*

4. $L_v/d = N_2$ *(industrial labor market clears)*

5. $L_a = N_1$ *(agricultural labor market clears)*

6. $\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{\tau})^\beta + \frac{1}{2\beta}$ *(definition of elasticity)*

7. $p_v = \min\{\min\{w_a\phi_1, w_x\phi_1\}, \frac{w_x\phi_2\varepsilon}{\varepsilon-1}\}$ *(profit maximization of industrial firm)*

8. $Q_v = \begin{cases} w_x\kappa/[\min\{w_a\phi_1, w_x\phi_1\} - w_x\phi_2] & \text{if } p_v = \min\{w_a\phi_1, w_x\phi_1\} \\ \kappa(\varepsilon-1)/\phi_2 & \text{if } p_v = w_x\phi_2\varepsilon/(\varepsilon-1) \end{cases}$

   (zero profit condition)

9. $Q_v = \frac{d\alpha[w_a N_a + w_x N_x]}{p}$ *(demand for variety v)*

10. $Q_v = \phi_2^{-1}(L_v - \kappa)$ *(supply of variety v)*

11. *No firm finds it profitable to use the less productive technology. Namely,* $\hat{\pi} < 0$

where $\hat{\pi}$ *equals*

$$
\begin{aligned}
\arg \max_{d',\varepsilon,p_v,Q_v} \quad & \{p_v Q_v - w_x^*(\kappa + Q_v \phi_1)\} \\
s.t. \quad & Q_v = \frac{2d'\alpha[w_a^* N_1 + w_x^* N_2]}{p_v} \\
& p^*[1 + (d^* - d')^\beta] = p_v[1 + d'^\beta] \\
& \varepsilon = 1 + \frac{(1 + d'^\beta)p_v}{[p_v^* \beta (d^* - d')^{\beta-1} + p_v \beta d'^{\beta-1}]d'}
\end{aligned}
$$

To be a Nash equilibrium, no firm should have an incentive to go back to the less productive technology. This is the meaning of the last condition in the above definition. The constraints in this last condition are the same as in the no-deviating condition for the *Symmetric Equilibrium with No Adoption*, except for the absence of a pricing constraint. There is no longer a pricing constraint because by assumption a deviating firm regains monopoly control over the use of the less productive technology. In this case a self-employed household can no longer produce the deviating firm's variety. Effectively, by deviating a firm is trading off a higher marginal cost with eliminating the pricing constraint.

4.5 Numerical Experiments

In this section we examine how the decision of industrial firms to use the more productive technology depends on the size of the economy's population. For a given parametrization, we first compute the prices and allocations that satisfy all but the no-deviation condition of the *Symmetric Equilibrium with Adoption* and the prices and allocations that satisfy all but the no-deviation condition of the *Symmetric Equilibrium with No Adoption.* 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. We repeat these steps varying the economy's population in order to determine how market size affects an economy's performance.

The main finding is that a *Symmetric Equilibrium with No Adoption* only exists for economies with a population sufficiently small and that a *Symmetric Equilibrium with*

Adoption exists only for economies with a population sufficiently large. Above some population size, the no-deviation condition in the *Symmetric Equilibrium with No Adoption* is violated, and below some population size, the no-deviation condition in the *Symmetric Equilibrium with Adoption* is violated. In other words, for smaller size economies, the only symmetric equilibrium is the one that uses the less productive technology, whereas for larger size economies, the only symmetric equilibrium is the one that uses the more productive technology.

The positive relation between population size and demand elasticity is key to understanding why larger markets stimulate the adoption of more productive technologies. That elasticity of demand is increasing in population is evident from the following differentiation:[12]

$$\frac{d\varepsilon}{dN_2} = \frac{(2/\kappa)^{\beta}\beta N_2^{\beta-1}}{2\beta(\beta+1)\varepsilon^{\beta} - (2\beta+1)\beta\varepsilon^{\beta-1}} \tag{17}$$

In taking this derivative, the technology of industrial firms is held constant. Since $\varepsilon > 1$, this expression is positive, so that an increase in N_2 leads to a greater elasticity of demand.

There are two reasons why the low elasticity of demand in small markets has a negative effect on technology adoption. First, when the elasticity is low, competition is weak, and the pre-adoption mark-up (and price) is high. In that case, the pricing constraint, required to deter competitive entry, imposes a relatively large price drop if a firm decides to adopt. As a result, profits from adopting are more likely to be negative. Second, when the elasticity is low, a given price drop leads to a smaller increase in total revenues. In an environment with relatively weak competition, lower prices do not lead to much gain in market share. These two forces explain why in small sized markets the entry constraint imposes a large cost on the adopting firm, enough so that profits are negative. As the market size increases and the elasticity of demand goes up, the entry constraint imposes a smaller cost on the adopting firm. Eventually, when the market size becomes sufficiently large, firms switch to the more productive technology, as the pricing constraint no longer prevents them from making positive profits.

We now report the findings for one parametrization of the model. The parameter

[12] By an increase in market size, we refer to a proportional increase in the measures of N, N_1 and N_2.

Table 1: Parameter values (first experiment)

$\beta = 1.05$	$\alpha = .60$
$\kappa = .70$	$\Omega_a = 1.0$
$N_1 = .4N$	$N_2 = .6N$
$\phi_1 = .1079$	$\phi_2 = .103$

values, which are reported in Table 1, were not chosen within the framework of a rigorous calibration exercise. Rather, they were chosen with the intent of illustrating the mechanism at hand in the clearest possible way. A virtue of this parametrization is that for all population sizes there exists a unique symmetric equilibrium. In particular, there exists a population size, $N^* = 116$, such that for $N < N^*$ only the *Symmetric Equilibrium with No Adoption* exists and for $N \geq N^*$ only the *Symmetric Equilibrium with Adoption* exists. Thus, for sufficiently small economies, the only equilibrium is one with no adoption; for sufficiently large economies, the only equilibrium is one with adoption.

To provide a more complete picture of the properties of the model, Table 2 reports for different population sizes the equilibrium distance between varieties, the elasticity of demand, the price of the industrial goods, the ratio of industrial to agricultural wages, and average indirect utility. Note that average indirect utility refers to the indirect utility of a household with an average wage $(w_a N_1 + w_x N_2)/N$ located at an average distance $d/4$ from its ideal variety:

$$\frac{w_a N_1 + w_x N_2}{N}(1-\mu)^{1-\mu}(\frac{\mu}{p(1+(d/4)^{\beta})})^{\mu}$$

Note also that average indirect utility in Table 2 has been normalized to 1 for the largest economy that does *not* adopt the more productive technology, i.e, $N = 115$.

Table 2 is divided into three parts. The first part corresponds to small economies where all firms use the less productive technology, $N < 116$. The second part corresponds to intermediate size economies where all firms use the more productive technology and the price ceiling to keep household from entering each firm's industry is binding, $116 \leq N \leq 475$. The third part corresponds to large economies where all firms use the more productive technology and the price ceiling to keep other households from entering the

Table 2: Symmetric equilibrium properties

N	d	ε	p_v	w_x/w_a	Indirect utility
Symmetric Equilibrium with No Adoption					
25	.259	5.5	.1316	1.0	.921
75	.142	9.1	.1212	1.0	.983
115	.113	11.2	.1185	1.0	1.00
Symmetric Equilibrium with Adoption (binding)					
116	.221	6.3	.1079	1.0	1.43
125	.206	6.7	.1079	1.0	1.045
175	.147	8.9	.1079	1.0	1.053
225	.114	11.1	.1079	1.0	1.058
275	.093	13.4	.1079	1.0	1.060
325	.079	15.6	.1079	1.0	1.062
375	.069	17.9	.1079	1.0	1.064
425	.060	20.2	.1079	1.0	1.065
475	.055	22.3	.1078	1.0	1.066
Symmetric Equilibrium with Adoption (nonbinding)					
525	.052	23.4	.1076	1.0	1.068
575	.050	24.5	.1074	1.0	1.069
625	.048	25.5	.1072	1.0	1.071
675	.046	26.5	.1070	1.0	1.072
725	.044	27.5	.1069	1.0	1.073
775	.043	28.4	.1068	1.0	1.074
825	.041	29.3	.1066	1.0	1.075
875	.040	30.2	.1065	1.0	1.076
925	.039	31.1	.1064	1.0	1.077

market is not binding, $N > 475$.

There are a number of features of the table worth pointing out. First, the relative wage of industrial workers is independent of the economy's size.[13] This is a consequence of Cobb-Douglas preferences. Second, the elasticity of demand and the number of varieties are non-monotonic functions of the size of the population. More specifically, there are one-time drops in the price elasticity and the number of varieties at the threshold population,

[13] To simplify the pricing constraint implied by adoption, we have purposely set the relative wage equal to 1 in this parametrization, exploiting the equilibrium relations that $w_x = \alpha N_1/((1-\alpha)N_2)$ and $w_a = \Omega_a$.

$N^* = 116$. This might seem inconsistent with the positive relation between market size and elasticity derived in (17), but it is not. At the threshold population, $N^* = 116$, firms switch to the more productive technology. Since adopting firms cannot sell above the price ceiling, this implies a substantial price drop, which in turn forces some firms to exit the market. This results in a lower price elasticity of demand and a smaller number of varieties produced.

This pattern contrasts with the average indirect utility, which is a monotonically increasing function of the economy's population. There are three reasons for the positive effect of market size on utility. First, larger markets lead to larger average firm size, implying more efficient production, lower prices 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; the third effect is specific to our model. To isolate the effect of switching to the more productive technology, Figure 2 compares the average indirect utility from Table 2 (solid curve) to what average indirect utility would be if the more productive technology were not available (dashed curve).[14] Until $N^* = 116$ the two curves coincide, because below that threshold firms do not have an incentive to switch to the more advanced technology. Once we reach the threshold though, firms adopt the more productive technology, and the utility jumps up. Thereafter, the difference between the two curves represents the contribution of technology upgrading to average indirect utility.

We end this section by pointing out that there is no conflict between firms and their workers in this model. This is to say that the results would be identical were we to assume that a firm's workers made the adoption decision and had claims to any profits or losses associated with that decision. For a population size $N^* < 116$, adoption implies

[14] This latter model is effectively the one studied by Hummels and Lugovskyy (2005).

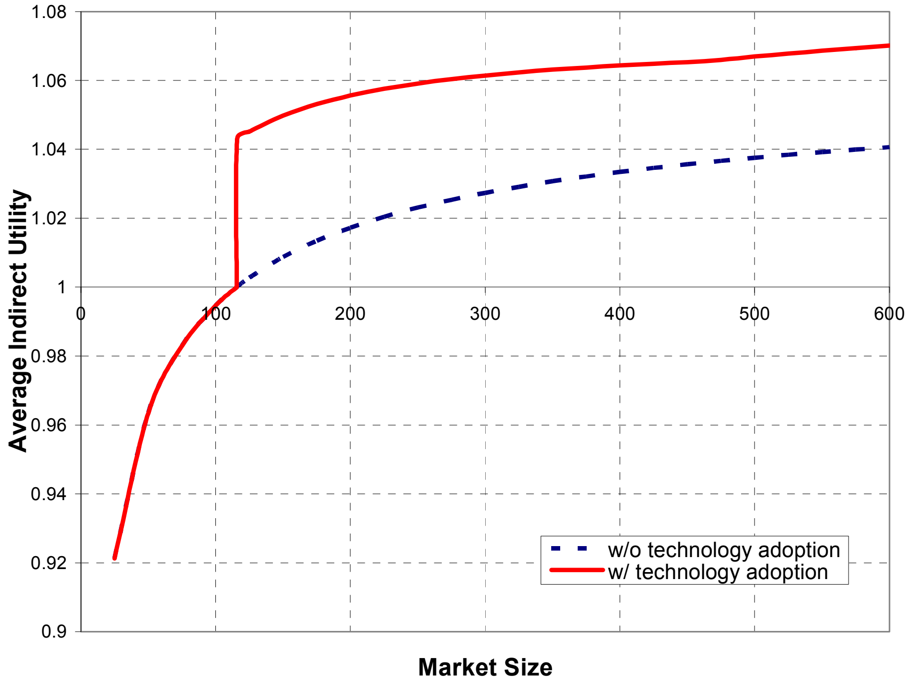

Figure 2: Effect of technology adoption on average indirect utility (first experiment)

negative profits, and thus, the earnings of a firm's workers would be lower under adoption. For a population size $N^* > 116$, adoption implies positive profits, and thus the earnings of workers in a deviating industry would be higher under adoption. An implication of this model is that workers would never resist their firm's attempt to adopt a more productive technology. As resistance by factor suppliers is a well documented phenomenon, in the next section we modify the model to allow for this possibility.

5 Adoption Cost #2: Skill Obsolescence

In this section we study the case where adoption is associated with skill obsolescence. While only Type-2 households possess the skills necessary to operate the less productive industrial technology, we assume Type-1 and Type-2 households are both equally adept at using the more productive technology. The underlying idea is that Type-2 households are skilled in the original (less productive) technology, but have no advantage in operating the new (more productive) technology. By switching to the more advanced technology, Type-2 households working in the adopting firm lose their privileged position and realize a loss in earnings, provided that the agricultural wage rate is lower than the pre-existing industrial wage rate.[15] This loss in earnings provides Type-2 workers with an incentive to resist the adoption of the more productive technology.

Industrial firms, in contrast, always prefer to use the more productive technology. As we drop the assumption that adoption is associated with the loss of monopoly control over the less productive technology, there is no longer any pricing constraint faced by an adopting firm. The more productive technology is still freely available. Regardless of the economy's population size, industrial firms now always have an incentive to adopt the more productive technology because the technology is better, $\phi_2 < \phi_1$, and the firm can hire workers at the lower agricultural wage rate.

As interests are no longer aligned, there is a conflict between a firm and its workers. We assume that a firm does not have the ability to adopt the more productive technology without its workers' consent. However, it does have the ability to commit to a redistribution plan whereby profits generated from the adoption are paid out to its workers in exchange for their consent. We assume that administration of this plan is costly so that only a fraction γ of the profits are actually redistributed to the workers, where $\gamma < 1$. These administrative costs could arise for a variety of reasons, one of these being the need to ex-post differentiate between Type-1 and Type-2 workers in an adopting firm.[16] If the remaining profits are enough to compensate the original workers for their falling wages, resistance stops, consent is given, and adoption occurs. If not, an industry must continue to use the less productive technology.

As we are primarily interested in examining how market size affects workers' resistance to technological change, we limit the subsequent analysis to the *Symmetric*

[15] This is so as long as the parameters of the model satisfy $w_x = \alpha N_1/((1-\alpha)N_2) > \Omega_a = w_a$.

[16] Alternatively, one could think of $1-\gamma$ as representing some type of union dues. We prefer the administration cost interpretation as union dues in the United States are a percentage of a worker's wages.

Equilibrium with No Adoption.[17] The existence of such an equilibrium means that Type-2 households resist and successfully block the adoption of the more productive technology in their respective industries. We first define a *Symmetric Equilibrium with No Adoption*, and then use numerical examples to illustrate how resistance and overcoming this resistance depend on the size of the market.

5.1 Symmetric Equilibrium with No Adoption

The main issue is whether a *Symmetric Equilibrium with No Adoption* exists. A necessary condition for the existence of such an equilibrium is that no single firm deviates and adopts the more productive technology. This deviation will occur if and only if the profits that are redistributed back to the Type-2 workers in the industry are large enough to compensate for their loss in earnings. The loss in earnings is $w_x - w_a$. As only a fraction γ of the adopting firm's profits are redistributed back to the firm's original workers, the necessary condition for workers to block the adoption of the the more productive technology is

$$\gamma \pi_v / L_v \leq w_x - w_a$$

where L_v refers to the original number of Type-2 workers in the firm, and π_v is the profit of the deviating firm.

Given the assumptions of the model, the definition of the *Symmetric Equilibrium with No Adoption* is as follows:

Definition 3 *A Symmetric Equilibrium with No Adoption (with workers' resistance) is a vector of prices and allocations* $(w_a^*, w_x^*, d^*, \varepsilon^*, L_v^*, L_a^*, Q_v^*, p^*, c_a^{1*}, c_a^{2*})$ *that satisfies Conditions 1-10 of Definition 1 and*

11'. Type-2 households find it profitable to block the adoption of the more productive

[17] Since the focus is on the adoption of more advanced technologies, we refrain from studying the *Symmetric Equilibrium with Adoption*. An additional reason we do not analyze the *Symmetric Equilibrium with Adoption* is that it is not entirely obvious how to specify the no-deviation condition in that case. Adopting firms typically employ both Type-1 and Type-2 households. Since their respective incentives to deviate are different, the no-deviation condition would depend on which households have the power within the firm.

technology. Namely, $w_a^* + \gamma\hat{\pi}_v/L_v^* \le w_x^*$*, where* $\hat{\pi}$ *equals*

$$\begin{aligned}
\arg \max_{d',\varepsilon,p_v,Q_v} \quad & \{p_v Q_v - w_a^*[Q_v\phi_2 + \kappa]\} \\
s.t. \quad & Q_v = \frac{2d'\alpha[w_a^* N_1^+ w_x^* N_2]}{p_v} \\
& p_v^*[1 + (d^* - d')^\beta] = p_v[1 + d'^\beta] \\
& \varepsilon = 1 + \frac{(1 + d'^\beta)p_v}{[p_v^*\beta(d^* - d')^{\beta-1} + p_v\beta d'^{\beta-1}]d'}
\end{aligned}$$

This last condition is the no-deviating condition for this economy. To be a Nash equilibrium, Type-2 workers in each firm must find it profitable to block the adoption of the more productive technology, given that all other firms do not adopt. This will be the case if the profits from adoption that are redistributed to the deviating firm's original workers do not suffice to bridge the gap between the industrial wage rate and the agricultural wage rate. The key difference between the no-deviating condition for this economy and the one analyzed in Section 4 is the absence of a pricing constraint.

5.2 Numerical Experiments

In order to examine how market size affects the incentives of workers to resist the adoption of the more productive technology, we parameterize the model, and compute the prices and allocations that satisfy all but the no-deviation condition of the *Symmetric Equilibrium with No Adoption*. We then determine whether a particular industry has the incentive to deviate. If no industry has such an incentive, we conclude that the *Symmetric Equilibrium with No Adoption* exists. To analyze how resistance depends on market size, we vary the size of the population, holding the fraction of Type-1 and Type-2 households constant.

We now report the findings for one parametrization of the model. As before, the parameter values were not chosen within the framework of some calibration exercise. Instead, they were chosen with the intention of illustrating the mechanism at hand in the clearest way. Table 3 gives the parameter values used.

Figure 3 presents the relative change in the earnings of the original workers in a deviating industry if workers give their consent and profits are redistributed back to them.

Table 3: Parameter values (second experiment)

$\beta = 1.01$	$\alpha = .615$
$\kappa = .25$	$\Omega_a = 1.0$
$N_1 = .4N$	$N_2 = .6N$
$\phi_1 = .101$	$\phi_2 = .1$
$\gamma = .75$	

More specifically, it equals $(\gamma\pi_v/L_v + w_a - w_x)/w_x$. As can be seen, if the population size is below $N^* = 33$, deviating and adopting the more productive technology leads to a drop in the original workers' earnings. Therefore, below this threshold, workers resist adoption, and the *Symmetric Equilibrium with No Adoption* exists. Once the population size rises above that cutoff, the original workers gain from technology adoption. As a result, their resistance breaks down, and firms switch to the more productive technology.

Here again, the positive relation between market size and elasticity of demand is key to understanding why larger economies are more likely to adopt the more productive technology. To see this, Table 4 reports a number of relevant statistics as they vary with the size of the economy's population. The table is divided into two parts: the first corresponds to those economies for which there exists a *Symmetric Equilibrium with No Adoption*; the second corresponds to those economies for which no such equilibrium exists. Thus, the second part lists the prices and allocations that satisfy all but the no-deviating condition of the *Symmetric Equilibrium with No Adoption.*

Again, as is evident from the second column, we see that as the size of the market increases, the elasticity of demand goes up. Neighboring varieties become closer substitutes. This means that for a given price drop, output (and total revenue) go up by more in larger markets, translating into greater profits.[18] This effect can be seen in column 4, which reports the profits of an adopting firm per original worker. Profits from adopting are always positive, but for smaller economies are not enough to compensate the original workers for a decline in their wage rate. This is reflected in column 3, which reports the

[18] As can be seen from column 5, the optimal price drop of a deviating firm does not vary much with market size.

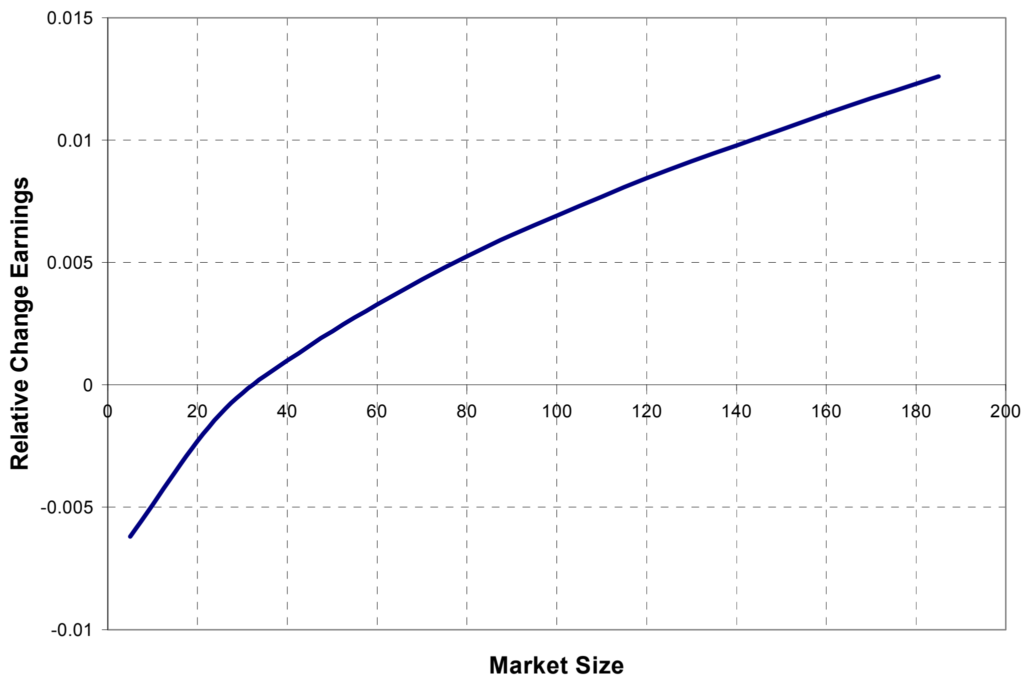

Figure 3: Technology adoption and relative change in earnings (second experiment)

relative change in workers' earnings if the technology were to be adopted. Once the market size reaches the threshold $N^* = 33$, a firm is able to compensate its original workers for the lower wages, and adoption occurs.

We emphasize that there is nothing special about this particular parametrization. We experimented with a number of other parametrizations and found qualitatively the same results. Note, however, that it is important for γ to be strictly less than one. The reason is straightforward. Take a firm that uses the less productive technology, and makes zero profits in equilibrium. If it were to pay its workers the lower agricultural wage and not change its output or price, profits per worker would exactly be equal to the difference between the industrial and the agricultural wage. If now that same firm were to use the more productive (and thus less costly) technology and not change its employment, then profits per worker would exceed the difference between the industrial and the agricultural wage. Therefore, if $\gamma = 1$ and all profits are redistributed, workers' earnings would exceed the original industrial wage, and there would never be any resistance to technology

Table 4: Symmetric equilibrium properties

Population N	Elasticity ε	Relative Change in real wages	Profits per worker	Change in industrial price
Symmetric Equilibrium with No Adoption				
5	4.3	-0.0062	0.058	-0.041
25	8.60	-0.0012	0.064	-0.038
Deviation and adoption of more productive technology				
45	11.27	0.0016	0.067	-0.038
65	13.40	0.0038	0.069	-0.037
85	15.21	0.0057	0.071	-0.037
105	16.83	0.0073	0.073	-0.037
125	18.30	0.0088	0.074	-0.037
145	19.66	0.0101	0.076	-0.037
165	20.93	0.0114	0.077	-0.037
185	22.12	0.0126	0.078	-0.037
205	23.25	0.0137	0.080	-0.037

adoption. Although this implies that for workers to oppose more productive technologies γ should be strictly smaller than 1, its value need not be small in any sense. Parameters can be chosen in such a way for resistance to arise for values of γ close to 1.

6 Concluding Remarks

This paper has explored how the elasticity of demand in larger markets may be key in understanding why free trade and market size stimulates technology adoption. 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. This makes it more likely for firms to upgrade their technology and less likely for their workers to resist adoption.

There are two main areas of future research implied by our theory. The first is to use the theory to shed light on a number of puzzles in the development and growth literature. One puzzle is 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^{th} century, population and transportation were insufficient in England to give people there the incentive to want to adopt new ideas. Another puzzle is why sub-Sahara African growth has been so disappointing since the end of colonial rule, especially in light of recent attempts to liberalize and privatize economies. Again, our theory offers a potential explanation for sub-Sahara Africa's disappointing development experience: economic reforms will not have large effects if the market size is too small on account of low population, isolation, and inadequate infrastructure, all of which describe the state of a large number of African countries. The second area of future research is to provide greater empirical support for our theory. One possibility is to use data on work stoppage and union membership at the industry and firm level to see if they relate to demand elasticities.

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