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# The Effects of the Market Structure on the Adoption of Evolving Technologies

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## Abstract

We study the speed at which technologies are adopted depending on how the market power is shared between the firms that sell technologies and the firms that buy them. Our results suggest that, because of a double marginalization problem, adoption is fastest when either sellers or buyers hold all the market power. Thus, competition between sides of the market may delay the adoption of technologies.

JEL Classification Numbers: L11, O33.

Keywords: Market Structures, Technology Adoption.

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## 1 Introduction

The adoption of new technologies is regarded as one of the main contributors to economic growth (see, for instance, Lucas (1993), Barro and Sala-i-Martin (1995)). The time at which a new technology is adopted has a significant impact on the growth rate of a country or a firm. Adopting new technologies too quickly may be disadvantageous given the sunk cost the establishment of a new technology carries. On the other hand, delaying the adoption of a new technology can lead to high opportunity costs or to a disadvantageous position with respect to competitors. This trade-off has been widely studied in the literature.

Most of the literature so far has focused on the pace of adoption of new technologies from the perspective of a firm which by adopting a new technology incurs in a fixed cost that is compensated over time by the increase in productivity. In this respect, the problem of adopting new technologies was reduced to two basic settings: an optimal stopping problem (Farzin et al. (1998) and Jovanovic and Nyarko (1996)) and a competition game between firms buying technologies (Götz (1999) and Chamley and Gale (1994)).

Two articles, Stoneman and Ireland (1983) and Ireland and Stoneman (1986), modify this approach and take into account the interaction between firms adopting new technologies, buyers, and the firms that sell these technologies, sellers. Stoneman and Ireland (1983) try to replicate the fact that the penetration of a new technology usually follows a sigmoid (S-shaped) path. On the other hand, Ireland and Stoneman (1986) focus on the role of expectations (rational and bounded rational) in the adoption of new technologies. We follow Stoneman and Ireland (1983) and Ireland and Stoneman (1986) in that we consider the interaction between sellers and buyers but focus instead on how the different market structures, i.e. how the market power is shared between supply and demand, affects the timing of the adoption of new technologies.

In the model we present sellers have a trade-off between price and time: setting up a higher price means that the income from selling the technology is higher. However, it also means that buyers wait more before adopting a new technology as technologies are more expensive. On the other hand, buyers have a trade-off between early adoption, which implies an earlier increase in productivity, and late adoption, which implies a greater (but later) increase in productivity since a newer technology is adopted. We explain how these trade-offs are solved when we consider three different market structures that are distinct in how the market power is shared among the buyers and the sellers.

In the first market structure we consider there is only one firm selling technologies and many firms willing to buy technologies. Hence, in this setting, the supply side holds all the market power and buyers act as price takers. In the second market setting considered in this

paper, there are many firms supplying technologies and only one firm interested in buying. In this setting the demand side holds all the market power and, therefore, sellers compete in prices and make profits equal to their outside option of not participating in the market. In the last market setting we consider there is one firm on each side of the market. In this last setting sellers and buyers compete for the surplus in the economy<sup>1</sup>.

We find that if there is competition between sellers and buyers then, because of a double marginalization problem, the adoption of new technologies occurs at a slower pace than when either sellers or buyers hold all the market power. This suggests that competition between both sides of the market, instead of competition within each side, can delay the adoption of new technologies. We round off our results by introducing some comparative statics.

The present paper tries to shed light on the speed of adoption of new technologies with respect to different market structures. Rather than focusing on the nature of the technology itself or other factors, we choose to study how market power can explain the differences in speed of adoption. We do not claim market power is the only reason why we might observe different behaviors. However, as we shall show, it is a factor that can explain these differences by itself.

From the theoretical point of view, many models study the optimal timing of technology adoption. Jovanovic and Nyarko (1996) present a model where the decision maker increases productivity by either learning by doing or by switching to a better technology. Karp and Lee (2001) extend this model by introducing discount factors. Farzin et al. (1998) introduce a setting where the increase in productivity caused by the adoption of the newest technology is known only in expected terms. Adopting a new technology has a sunk cost that is independent of the productivity level of the new technology. In an article by Doraszelski (2004) a distinction between technological breakthroughs and engineering refinements is introduced. Other papers that consider the adoption of new technologies from the point of view of the agents adopting the technologies (buyers) are Chamley and Gale (1994) and Götz (1999).

From the empirical perspective, there is no doubt that the timing of technology adoption has been a concern. Hoppe (2002) presents a literature review on this topic. To cite some, Karshenas and Stoneman (1993) present a study on the diffusion of CNC (computer numerically controlled machine tools) in the UK engineering industry. Factors determining the delaying in the adoption of the new technology were found to be, among others, the learning effects and the cost of the new technology. Weiss (1994) studied the adoption of a new process technology called the surface-mount technology by printed circuit board manufacturers.

The rest of the paper is organized as follows. In section 2 we introduce the model. Section

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<sup>1</sup>The many sellers to many buyers case is redundant as we discuss in Section 3.4.

3 presents our findings for the three different market structures considered. In section 4 we present a comparative statics analysis. Finally, section 5 concludes.

## 2 The Model

Consider a continuous time model where the two sides of the market, supply and demand, play a repeated game. On the supply side of the market there are  $n_s \geq 1$  sellers (firms that sell technologies). On the other hand, the demand side of the market has  $n_d \geq 1$  buyers (firms that buy technologies). An exogenous process determines the appearance of new technologies that are sold by sellers to buyers. Sellers have to decide a price for these technologies. On the contrary, buyers produce output given an initial level of technology and decide when to buy a new technology. All firms are assumed to be risk neutral and have common knowledge.

As an illustrative example, consider the case of micro-processors for computers. Intel<sup>TM</sup>, represented in the model by the exogenous process creating new technologies, develops new microprocessors. These microprocessors are sold by computer manufactures, sellers, to consumers, buyers. Consumers deriving utility from buying computers with microprocessors are represented in the model by buyers producing output given a level of technology.

Technologies are denoted by  $\theta \in \mathbb{R}$  where higher  $\theta$  means that the technology is more efficient. Buyers are all endowed with the same initial level of technology,  $\theta_0 > 0$ . As a simplification, we assume that only two different technologies coexists in the economy at any given point in time  $t$ . These are the initial level of technology,  $\theta_0$ , and the newest technology,  $\theta_t$ . Sellers have no control over the release of new technologies. They own the newest technology and their role is to price it. If a seller sells a given technology  $\theta$ , then it has to pay a fix cost  $C > 0$  for the transaction to take place. In our example above,  $C$  can be regarded as the price computer manufacturers pay to Intel<sup>TM</sup> for a microprocessor.

From  $t$  to  $t + dt$  a new technology  $\theta_{t+dt} = \theta_t + d\theta_t$  is introduced, where

$$d\theta_t = \alpha\theta_t dt + \sigma\theta_t dz_t.$$

We assume that  $\alpha, \sigma > 0$  and  $z$  is a Brownian Motion. Therefore,  $\theta$  evolves according to a Geometric Brownian Motion. The assumption that the evolution of technologies follows a Geometric Brownian Motion is made simply for analytical convenience. Closed form solutions can be found for this dynamics but not for other dynamics that could be used, like Poisson processes or standard Brownian Motion. The use of different dynamics does not affect how supply and demand interact and how the market power affects the speed of adoption, which is the target of this paper<sup>2</sup>.

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<sup>2</sup>Moreover, the timing of adoption depends on the time the process on technologies is expected to hit a

Note that at any point in time there may be technological regress,  $\theta(t + dt) < \theta(t)$ . This fact has no implications for the model and our results as if it is optimal not to buy the technology  $\theta$  at a given price then it is not optimal to buy technology  $\tilde{\theta} < \theta$  at this same price. To interpret technological regress we can assume that some of the new technologies that are created simply do not improve on the previous technology and are never made public.

Following Doraszelski (2004) and Dixit and Pindyck (1994) we assume that the adoption of a new technology is a one-time irreversible decision. Doraszelski (2001) shows that the buyer's decision problem if we allow it to buy new technologies more than once is of the same form after each adoption of a new technology<sup>3</sup>. Similarly, we assume that each seller only sells technologies once. This latter assumption is made for analytical convenience as it reduces the strategy space in a more tractable way.

The timing of the game played between sellers and buyers is as follows: At every period  $t > 0$  each seller  $i \in \{1, \dots, n_s\}$  decides a price  $I_i \geq 0$  for the technology  $\theta_t$ . Then, given the current level of technology  $\theta_t$ , buyers that still employ technology  $\theta_0$  decide whether to buy the technology  $\theta_t$  at given prices  $\{I_i\}_{i=1}^{n_s}$  or to wait. We do not need to specify how the market clears given prices and buyers' decisions as it will be clear later on.

Let  $H(t)$  be the history of prices, technologies, and decisions of the buyers up to period  $t$ . Thus,  $h(k) \in H(t)$  for  $k \leq t$  consists of the level of technology at time  $k$ ,  $\theta_k$ , the prices set by all sellers  $\{I_i\}_{i=1}^{n_s}$ , and the decision of the buyers that still employ technology  $\theta_0$  of whether to buy the technology  $\theta_k$  at prices  $\{I_i\}_{i=1}^{n_s}$  or not.

A strategy for a seller  $i \in \{1, \dots, n_s\}$  consists of a price  $I_i > 0$  that depends on all previous history  $H(t)$ . That is,  $I_i : H(t) \rightarrow \mathbb{R}^+$ . Note that we are using  $I_i$  for both the action and the strategy. This should not give rise to any confusion in our context. A strategy for a buyer consists of the function  $S : H(t) \times \{I_i\}_{i=1}^{n_s} \times \theta \rightarrow d$  where  $d = \{\text{buy, wait}\}$  is the decision of whether to buy the technology  $\theta$  at prices  $\{I_i\}_{i=1}^{n_s}$  or to wait. Given that a buyer can only upgrade its technology once, we assume that once a buyer upgrades its technology it leaves the market. The equilibrium concept we use throughout the paper is the standard Nash equilibrium (NE for short).

After adopting a new technology  $\theta$  at price  $I$ , the discounted stream of profits of a buyer is given by

$$\int_0^{\infty} \pi(\theta) e^{-rs} ds - I = \frac{\pi(\theta)}{r} - I$$

certain threshold  $\theta^*$  to be introduced later. Thus, given the appropriate calibration of parameters, it does not matter which specific dynamics we use.

<sup>3</sup>As Doraszelski (2001) argues, buyers' decision reduces to solving the trade-off between adopting a new technology now or waiting for a better technologies to appear. This trade-off remains unchanged if buyers can upgrade their technology more than once.

where  $\pi(\theta)$  is the instantaneous profit from using technology  $\theta$  and  $r > 0$  is the interest rate. We assume  $\pi$  to be strictly increasing on  $\theta$ . For deriving our results we use a specific functional form for  $\pi$  that can be obtained from the Cobb-Douglas production function. Therefore, following Farzin et. al. (1998), we have that  $\pi(\theta) = \phi\theta^b$  where  $\phi > 0$  and  $b > 1$ .

When a technology  $\theta$  is sold, the seller has to pay a fixed cost  $C > 0$  for the transaction to take place. A necessary assumption is that  $C < \pi(\theta_0)/r$ . If technology  $\theta$  is sold at price  $I$  at time  $t$  then the present value of the profits of the seller are given by

$$(I - C) E(e^{-rt}).$$

In case a set of buyers want to buy a given level of technology at the same price from the same seller, then each of these buyers has equal probability of making the purchase. Similarly, if a set of sellers wants to sell a given technology at the same price to the same buyer, then each of these sellers has equal probability of selling the technology.

We define  $\theta^*$  as the value of  $\theta$  at which the first purchase of a new technology takes place. The value of  $\theta^*$  is our measure of the speed at which new technologies are adopted; Higher  $\theta^*$  means that more time has to pass before the first adoption of a new technology takes place.

### 3 Speed of Adoption

#### 3.1 The Supply Side Holds All the Market Power

In this subsection we consider the situation where there is one seller,  $n_s = 1$ , and at least 2 buyers,  $n_d \geq 2$ . Given that the seller can only sell technologies once and that there is more than one buyer, a necessary condition for a pair  $(I, \theta^*)$  to be a NE is that the increase in profits of the firm that buys the technology must be zero. Otherwise, either we can find a buyer willing to pay more than  $I$  for the technology  $\theta^*$  or the seller is making negative profits. Note that we omit the subscript in  $I$  as there is only one seller. A condition for NE is then

$$\frac{\pi(\theta^*)}{r} - I = \frac{\pi(\theta_0)}{r}. \quad (1)$$

The problem of the seller is to maximize its expected profits given the trigger level  $\theta^*$ . Let  $\tau$  denote the hitting time of  $\theta$  on  $\theta^*$ . Therefore,  $E(e^{-r\tau})$  gives the expected discount factor at which the seller evaluates selling the technology. We can compute the value of  $E(e^{-r\tau})$  using the analysis found in Dixit and Pindyck (1999) (this analysis is reproduced in appendix A.1). The expected discount factor is given by

$$E(e^{-r\tau}) = \left( \frac{\theta}{\theta^*} \right)^\beta,$$



where  $\beta > 1$  is given by

$$\beta = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}}. \quad (2)$$

The seller chooses  $I$  to maximize profits:

$$\max_I (I - C)E(e^{-r\tau})$$

where the relationship between  $I$  and  $E(e^{-r\tau})$  is given via the relationship between  $I$  and  $\theta^*$  from equation (1).

The first order condition yields

$$\frac{1}{\beta(I - C)} = \frac{\pi^{-1'}(\pi(\theta_0)) + rI}{\pi^{-1}(\pi(\theta_0) + rI)} r.$$

In order for the optimal price  $I$  not to explode we need the following condition on  $\beta$ :

**Assumption 1.**

$$\beta > \lim_{x \rightarrow \infty} \frac{\pi^{-1}(x)}{x\pi^{-1'}(x)}$$

Assumption 1 is satisfied by the Cobb-Douglas production function if  $\beta > b$ . After substituting  $\pi(\theta) = \phi\theta^b$  we obtain

$$\theta^* = \left[ \frac{\beta}{\beta - b} \left( \theta_0^b + \frac{r}{\phi} C \right) \right]^{1/b}, \quad (3)$$

$$I = \frac{b}{\beta - b} \frac{\phi}{r} \theta_0^b + \frac{\beta}{\beta - b} C. \quad (4)$$

### 3.2 The Demand Side Holds All the Market Power

In this case we have that  $n_s \geq 2$  and  $n_d = 1$ . Given that there is only one firm buying technologies and that the firm buying technologies can only buy a new technology once, sellers compete to the point where in equilibrium their profits are zero. Therefore, an equilibrium condition is that for at least two sellers  $i, j$

$$I_i = I_j = C$$

while  $I_k \geq C$  for  $k \neq i, j$ . Denote  $I = I_i = I_j$ .

The problem of the buyer is

$$\max_{\theta^*} E_\tau \left( \int_0^\tau \pi(\theta_0) e^{-rs} ds + \int_\tau^\infty \pi(\theta^*) e^{-rs} ds - I e^{-r\tau} \right).$$

Taking first order conditions and using the Cobb-Douglas production function we obtain the equilibrium values (see appendix A.2 for details):

$$\theta^* = \left[ \frac{\beta}{\beta - b} \left( \theta_0^b + \frac{r}{\phi} C \right) \right]^{1/b}, \quad (5)$$

$$I = C. \quad (6)$$

Note that the equilibrium level of  $\theta^*$  when the demand holds all the market power, (5), is the same as the one obtained when the supply has all the market power, (3). The value of  $\theta^*$  in these two cases maximizes the total surplus in the economy:

**Proposition 1.** *The value of  $\theta^*$  when only one side of the market holds all the power (sections 3.1 and 3.2) maximizes total surplus in the economy.*

*Proof.* We solve for value of  $\theta^*$  that maximizes total surplus in the economy by choosing the value of  $\theta^*$  that maximizes the sum of profits of each pairwise interaction between demand and supply<sup>4</sup>.

$$\max_{\theta^*} (I - C) \left( \frac{\theta}{\theta^*} \right)^\beta + \left( \frac{\pi(\theta^*)}{r} - I - \frac{\pi(\theta_0)}{r} \right) \left( \frac{\theta}{\theta^*} \right)^\beta.$$

The first order condition of the problem above leads to

$$\theta^* \pi'(\theta^*) + \beta \pi(\theta^*) - \beta r C - \beta \pi(\theta_0) = 0.$$

Using the Cobb-Douglas production function and after some algebra we obtain

$$\theta^* = \left[ \frac{\beta}{\beta - b} \left( \theta_0^b + \frac{r}{\phi} C \right) \right]^{1/b}. \quad (7)$$

Comparing the values of  $\theta^*$  in equations (3), (5) and (7) gives the desired result.  $\square$

The intuition behind the result in Proposition 1 is the following: Consider the case where the supply holds all the market power. In this situation, the firm selling technologies has total control over the market and can exercise perfect price discrimination to any of the buyers. Thus, the seller extracts maximum surplus in the economy. As shown in Proposition 1, this is done by choosing the appropriate value for  $\theta^*$ .

Consider now the case where demand holds all the market power. In this case the buyer is the one in control of the market and is the one who can extract maximum surplus: sellers

<sup>4</sup>Note that this is the same as solving for the Nash bargaining solution (Nash (1950)) of the game between a firm in the supply side and a firm in the demand side

set up a price equal to their marginal costs ( $C$ ) and, thus, the buyer simply chooses the right, i.e. profit maximizing, time to adopt a new technology. Again this results in choosing the value of  $\theta^*$  that maximizes total surplus.

The difference between the two settings considered so far (sections 3.1 and 3.2) lies in the way market surplus is distributed. When the supply holds all the market power then the price (4) is such that the unique seller collects all the surplus. On the other hand, when the demand holds all the market power, the price (6) is such that the unique buyer takes all the surplus.

### 3.3 Competition between Supply and Demand

For this setting we assume that there is a bilateral duopoly  $n_s = 1$  and  $n_d = 1$ <sup>5</sup>. We solve for the NE by backwards induction. First, we compute the best response of the buyer for any given pair  $(I, \theta)$ . Then, given the best response  $\theta^*$ , we compute the optimal price  $I$ . We omit the subscript in  $I$  again as there is only one seller.

The problem of the buyer is:

$$\max_{\theta^*} E_{\tau} \left( \int_0^{\tau} \pi(\theta_0) e^{-rs} ds + \int_{\tau}^{\infty} \pi(\theta^*) e^{-rs} ds - I e^{-r\tau} \right).$$

The first order condition of the problem leads to (see appendix A.3 for details)

$$\pi(\theta^*)\beta - \pi'(\theta^*)\theta^* = \beta(rI + \pi(\theta_0)). \quad (8)$$

The objective function of the seller is:

$$\max_I \theta^{*\beta} (I - C).$$

The first order condition leads to

$$-\pi(\theta^*)\beta^2 + \pi'(\theta^*)\theta^*(2\beta - 1) - \pi''(\theta^*)\theta^{*2} + \pi(\theta_0)\beta^2 + \beta^2 rC = 0. \quad (9)$$

If we assume a Cobb-Douglas production function, from (8) and (9) we obtain

$$\begin{aligned} \theta^* &= \left[ \left( \frac{\beta}{\beta - b} \right)^2 \left( \theta_0^b + \frac{r}{\phi} C \right) \right]^{1/b}, \\ I &= \frac{b}{\beta - b} \frac{\phi}{r} \theta_0^b + \frac{\beta}{\beta - b} C. \end{aligned} \quad (10)$$

Hence, given assumption 1 and what we can infer from (3), (5) and (10), with competition between supply and demand the adoption of technologies is expected to occur at a slower rate:

<sup>5</sup>The case where  $n_s, n_d > 1$  is discussed in the next subsection

**Proposition 2.** *The value of  $\theta^*$  under competition between supply and demand (section 3.3) is higher than when one side of the market holds all the power (sections 3.1 and 3.2).*

*Proof.* Follows from (3), (5) and (10). □

The key to the result is the following: Both sides of the economy sharing market power creates a double marginalization problem and, thus, an inefficiency. This inefficiency is translated into  $\theta^*$  being higher than its social maximizing value and, thus, the adoption of new technologies is delayed.

The double marginalization problem arises as a result of the game between the seller and the buyer in the same fashion as it arises between a wholesaler and a retailer<sup>6</sup>. The seller prices technologies optimizing its profit; technologies are then bought by the buyer at the point in time it considers optimal. This double not-joint optimization is what gives rise to the efficiency loss that is present in the model in the form of a later adoption.

### 3.4 Discussion

A setting with many buyers and many sellers ( $n_d, n_s > 1$ ), although more realistic, adds no new insight to the three cases we have already considered in this paper. If there are more buyers than sellers, then given that buyers buy only once and sellers sell only once, sellers still hold all the market power as they are outnumbered by buyers. That is, every seller always finds a buyer while not every buyer finds a seller. Thus, this setting reduces to the situation we consider in Section 3.1. A similar thing occurs if there are more sellers than buyers.

In a situation where there are the same number of buyers and sellers, both sides of the market share market power in exactly the similar way as when  $n_s = n_d = 1$ : each seller can always find a buyer and each buyer can always find a seller. Thus, this case reduces to the situation we consider in Section 3.3

## 4 Comparative Statics

We present some comparative static results in Figure 1. The graphs in Figure 1 depict the response of the level of technology adopted,  $\theta^*$ , and the expected discount factor, which is our measure of the speed at which new technologies are adopted, to the different parameters of the model. In particular, we explore the changes in these two variables when the variance of

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<sup>6</sup>Similarly, consider a Stackelberg game between sellers, who move first by setting the price, and buyers, who given the price decide when to upgrade technologies

the process governing the evolution of technologies  $\sigma$ , the trend or the expected evolution of technology  $\alpha$ , and the interest rate  $r$ , change. The value of the parameters  $\phi, b, r$  and  $\theta_0$  are set to the same values as in Farzin et. al. (1998). The value of  $\theta, \alpha$  and  $\sigma$  are set such that the expected discount factor implies a delay in the adoption of new technologies of around 16 periods, which is about the value Farzin et al. (1998) use (17.79 periods in their paper). The value of the parameters we use are then  $\phi = 151.32, b = 1.25, r = 0.1, \theta_0 = 1, \theta = \theta_0, \alpha = 0.05$  and  $\sigma = 0.01$ .

From Figure 1 there are three facts that are worth noting. First, an increase in either  $\alpha$  or  $\sigma$  has bigger effect in the level of the technology adopted when there is competition between supply and demand. Hence, when only one side of the market holds all the power the level of technology adopted is less sensitive to the process governing the evolution of technologies. The explanation for this fact is the following: When there is competition between supply and demand, the changes in the parameters governing the evolution of technologies are taken into account twice, once per each optimization problem. This can be seen in the differences between (3), (5) and (10), where the term  $\frac{\beta}{\beta-b}$  appears with a higher exponent in (10)<sup>7</sup>. That is, the market overreacts to the changes in  $\alpha$  and  $\sigma$  when there is competition between supply and demand.

A second feature that deserves attention is that as the interest rate rises, the level of technology that is adopted tends to converge to the same value under both competition between supply and demand and the case when only one side holds all the market power. This suggest that in economies with high interest rates, the structure of the market for technologies has less effect in the adoption of new technologies than when compared with low interest rate economies. With higher interest rates, the opportunity cost of waiting increases and, therefore,  $\theta^*$  decreases. However, this increase in opportunity cost is more significant when one side holds all the market power. Assume, for instance, that sellers hold all the market power. In such situation, the opportunity cost of not adopting earlier as interest rates increase is higher than when compared with the situation when there is competition between supply and demand. This is the case as if there are many buyers and only one seller then each buyer faces the risk of another buyer coming in and being to first one to upgrade its technology.

A third fact which the numerical analysis reveals is that the effects of the variance of the process for technology,  $\sigma$ , has a small effect if any on the speed of adoption. That is, industries where there the evolution of technologies is very random with big improvements in short time-space and periods with almost no improvements should not influence the speed at which the adoption occurs. As discussed earlier when we presented the model, this is due to

<sup>7</sup>We remind the reader that  $\alpha$  and  $\sigma$  influence  $\theta^*$  via  $\beta$  (see equation (2)).

the fact that the speed of adoption is determined by the time the process on technologies is expected to hit the threshold  $\theta^*$ , which depends mostly on the trend  $\alpha$  and not the variance  $\sigma$ .

## 5 Conclusions

In this paper we investigated how different market structures affect the speed at which new technologies are adopted. A game between the demand side, firms buying technology, and the supply side, firms selling technology, was presented. Three different market scenarios were considered, one in which the supply holds all the market power, another in which the demand holds all the market power, and a third setting where there is competition between both supply and demand.

In our results, we explained how these three different market structures affect the adoption of technologies. The speed of adoption when one side of the market holds all the market power is the same independently of which side holds the power. However, when no side of the economy has all the market power, the competition between supply and demand case, then the adoption occurs at a slower pace. This suggests that competition between the two sides of the market might decrease the speed of adoption and that competition within each side might increase the speed of adoption.

The literature so far has focused mostly on the optimal timing of adoption of new technologies from the perspective of a firm that faces an exogenous process of technological change where the price of new technologies is also exogenous. To our knowledge, this is the first paper to consider how the differences in market structure can affect the speed of adoption of new technologies. Empirical studies often attributed the differences in the speed of adoption of technologies to the nature of the technology itself. We show that the market structure could also account for these differences in speeds of adoption.

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## APPENDIX

## A.1 DERIVATION OF THE EXPECTED DISCOUNT FACTOR

Note that, for a given  $\theta^*$ , the only variable the expected discount factor depend on is the current level of technology  $\theta$ . Then we can define the function  $f$  as

$$f(\theta) = E(e^{-r\tau}).$$

If  $\theta = \theta^*$  then it is obvious that  $\tau = 0$  and hence  $f(\theta^*) = 1$ . Assume then that  $\theta < \theta^*$ . Choose  $dt$  small enough so that  $\theta$  won't surpass  $\theta^*$  in the next time interval. Then we have that the problem of computing the hitting time restarts at the point  $\theta + d\theta$ . That is,

$$\begin{aligned} f(\theta) &= e^{-rdt} E(f(\theta + d\theta)) \\ &= e^{-rdt} [f(\theta) + E(df(\theta))]. \end{aligned} \quad (11)$$

Given that  $\theta$  follows a Geometric Brownian Motion we can expand  $df(\theta)$  using Itô's Lemma. In this case we get

$$df(\theta) = (\alpha\theta dt + \sigma\theta dz) f'(\theta) + \frac{1}{2}\sigma^2\theta^2 f''(\theta) dt.$$

Note that  $E(dz) = 0$ . Furthermore, using the Taylor expansion and ignoring the terms of order  $dt^2$  and higher we can state that  $e^{-rdt} = 1 - \rho dt$ . Hence,

$$e^{-rdt} E(df(\theta)) = (1 - \rho dt)\alpha\theta f'(\theta) dt + \frac{1}{2}\sigma^2\theta^2 f''(\theta) dt.$$

Therefore, ignoring once more the terms of order equal or higher than  $dt^2$ , we get that

$$0 = -\rho f(\theta) + \alpha\theta f'(\theta) + \frac{1}{2}\sigma^2\theta^2 f''(\theta). \quad (12)$$

Equation (12) is a second order linear differential equation in  $f$  with the boundary conditions  $f(\theta^*) = 1$  and  $f(\theta) \rightarrow 0$  as the difference  $\theta^* - \theta$  becomes large. The general solution to the second order linear differential equation is given by

$$f(\theta) = C_1\theta^\beta + C_2\theta^{\beta'}$$

where  $\beta$  and  $\beta'$  are the roots to the characteristic equation in  $x$

$$0 = -\rho + \alpha x + \frac{1}{2}\sigma^2 x(x-1).$$

Let  $\beta$  be the positive root exceeding unity to the above equation, that is

$$\beta = \frac{1}{2} - \frac{\alpha}{\sigma^2} + \sqrt{\left(\frac{\alpha}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}}. \quad (13)$$



Using the terminal conditions we can set  $C_1 = \theta^{*\beta}$  and  $C_2 = 0$ . This leads to

$$f(\theta) = \left(\frac{\theta}{\theta^*}\right)^\beta$$

where  $\beta$  is given in equation (13). Recalling that  $f(\theta) = E(e^{-r\tau})$  gives the desired result.

## A.2 PROBLEM OF THE FIRM FROM THE DEMAND SIDE WHEN THE DEMAND HOLDS ALL THE MARKET POWER

The problem of the buyer is given by

$$\max_{\theta^*} E \left( \int_0^\tau \pi(\theta_0) e^{-rs} ds + \int_\tau^\infty \pi(\theta^*) e^{-rs} ds - I e^{-r\tau} \right).$$

After computing the integrals above the maximization problem becomes

$$\max_{\theta^*} \left\{ \pi(\theta_0) E \left( \frac{1}{-r} e^{-r\tau} \right) + \pi(\theta^*) E \left( \lim_{x \rightarrow \infty} \frac{1}{-r} e^{-rx} - \frac{1}{-r} e^{-r\tau} \right) - I E(e^{-r\tau}) \right\}.$$

Which in turn can be rewritten as

$$\max_{\theta^*} \left\{ \frac{\pi(\theta_0)}{r} E(1 - e^{-r\tau}) + \frac{\pi(\theta^*)}{r} E(e^{-r\tau}) - I E(e^{-r\tau}) \right\}. \quad (14)$$

Plugging in the value of  $E(e^{-r\tau})$ , using the fact that  $I = C$  and dropping the constants from the maximization problem we get that

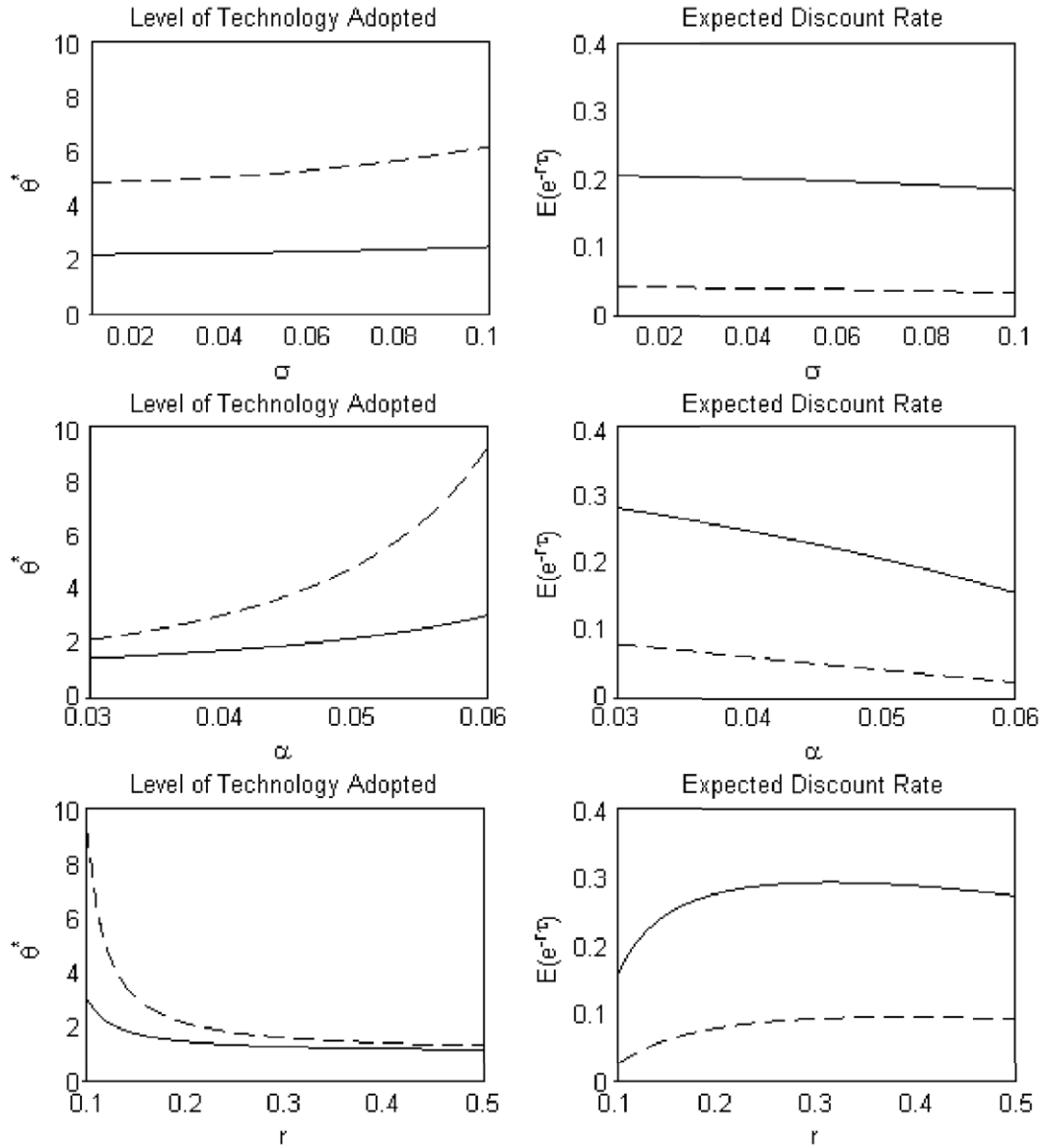
$$\max_{\theta^*} \theta^{*\beta} (\pi(\theta^*) - \pi(\theta_0) - rC).$$

## A.3 PROBLEM OF THE FIRM FROM THE DEMAND SIDE UNDER COMPETITION BETWEEN SUPPLY AND DEMAND

The same analysis applies here as in Appendix A.3 to get equation (14). From this equation, by plugging the value of  $E(e^{-r\tau})$  and dropping the constants from the maximization problem we get that

$$\max_{\theta^*} \theta^{*\beta} \left( \frac{\pi(\theta^*)}{r} - \frac{\pi(\theta_0)}{r} - I \right).$$

Figure 1: Comparative Statics



The dashed line corresponds to the case where there is competition between supply and demand while the continuous line corresponds to the case where the market power lies with only one side of the economy.