Die approbierte Originalversion dieser Diplom-/Masterarbeit ist in der Hauptbibliothek der Technischen Universität Wien aufgestellt und zugänglich.
http://www.ub.tuwien.ac.at

The approved original version of this diploma or master thesis is available at the main library of the Vienna University of Technology.
http://www.ub.tuwien.ac.at/eng

Institut für Höhere Studien
Institute for Advanced Studies
Vienna

Continuing Education Center

MSc Economics

Intensity of competition and technological progress

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by

Dr. Klaus Ritzberger

Bozidar Plavsic

1425503

Vienna, June 6, 2016

MSc Economics

Affidavit

I, Bozidar Plavsic

hereby declare

that I am the sole author of the present Master's Thesis,

Intensity of competition and technological progress

19 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, June 6, 2016

Signature

Contents

List of Figures

Abstract

The empirical phenomenon that in monopolized markets technological improvements are small compared to competitive markets is to be examined. The level of technological advancements has been measured by how big improvement a new technology represents compared to the current best technology used in the market. The relationship between intensity of competition and technological progress has been examined in a model where R&D laboratory exerts effort, which is translated into a new technology, such that its profits are maximized. It is shown that intensity of competition affects the amount of technological progress in a non-monotone way.

1 Introduction

As an important ingredient of economic growth, technological progress has been in the heart of interest of many economists, both from micro and macro viewpoint. Efforts have been made in establishing the influence of technology improvements on growth, understanding how a firm makes a decision whether to innovate or not, attempting to measure the progress empirically. Additionally, some of the questions raised are concerned with how organisation of an industry affects technological advance. A small piece of this relationship will be examined in this paper.

Basically, the focus of the paper is on explaining how intensity of competition among the firms influences the level of technological advance. This levl of technological advance has been measured by how big improvement a new technology represents compared to the current best technology used in the market. Empirical evidence shows that in monopolized markets technological progress is represented by innovations which are small improvements forward. On the other hand, purely competitive markets provide an incentive for large technological advancements. This phenomenon is to be captured by the model.

The model here represents the extension of the one in Boone (2001). What differs here is the way in which the research and development side has been modeled. More attention has been placed on R&D laboratory, that now maximizes its own profits, apart from providing firms with a new technology. The R&D laboratory introduces a process innovation, lowering marginal costs of production, and does that by exerting effort. This effort will be called productivity in the model. After observing conditions on the market, R&D laboratory decides how productive it will be by maximizing its profits.

It turns out that this productivity is low when the intensity of competition is weak, which results in small improvements of the current best technology. On the other hand, with intensity of competition being very high, R&D laboratory maximizes its profits for a high productivity. In this case, innovations are major steps forward and technological advance is big. This is so, because the identity of the firm that buys the innovation changes with the intensity of competition.

Moreover, it has been shown that technological advance does not monotonically increase with the intensity of competition. When competition is weak, it turns out that the buyer of the innovation is the high cost firm. As competition becomes more intense, strategic effects among firms come into play, lowering the profits from acquiring a new technology, which results in a decrease of R&D productivity. Opposite to this, when the intensity of competition is high, a low cost firm buys the innovation in order to increase its dominance. As competition becomes more severe, escaping from the opponents is more fruitful for the firm, so it values the innovation even more. Consequently, a profit maximizing R&D laboratory increases its own productivity. To put things together, a non-monotone relation between intensity of competition and technological progress has been established.

This paper confronts two sides of the innovation process: An R&D laboratory that produces a new technology and firms that want to apply it in their production process. It makes an attempt of observing the behavior of both of these sides. Furthermore, this paper shows how the lower of technological advance is influenced by intensity of competition.

For an introduction to the role of industrial organization in R&D see Tirole (1988). Further literature on the relationship between market structure and firms' incentives to innovate is quite extensive. Papers by Loury (1979), Lee and Wilde (1980) and Dasgupta and Stiglitz (1980a,b) can provide further insights. Of course, since the present paper represents the extension of it, Boone (2001) also adds to the understanding how intensity of competition influences decision to innovate.

The paper is organised in the following fashion. Section 2 gives an overview of the literature involved in establishing the empirical relationship between the intensity of competition and technological progress. In section 3, the framework used to obtain the results has been outlined. Section 4 provides the obtained results for the case of duopoly. In the fifth section, an example has been given that illustrates the results and shows that they hold for the case of three firms competing against each other. In the last section, conclusions are drawn.

2 Empirical evidence

As stated in Kamien and Schwartz (1982: 84) "*the heart of the Schumpeterian theory [is that] (...) monopoly power is conductive to technical advance*". So, defined broadly, Schumpeter's hypothesis would state that a positive relationship exists between monopoly power and innovation. Therefore, from his viewpoint government should be more tolerant toward monopolistic practices, as stated in *Capitalism, Socialism and Democracy* (1975):

> *Thus it is not sufficient to argue that because perfect competition is impossible under modern industrial conditions - or because it always has been impossible - the large-scale establishment or unit of control must be accepted as a necessary evil inseparable from the economic progress which it is prevented from sabotaging by the force inherent in its productive apparatus. What we have got to accept is that it has come to be the most powerful engine of that progress and in particular of the long-run expansion of total output only in spite of, but to a considerable extent through, this strategy which looks so restrictive when viewed from the individual point of time. In this respect, perfect competition is not only impossible, but inferior, and has no title to being set up as a model of ideal efficiency. It is hence a mistake to base the theory of government regulation of industry on the principle that big business should be made to work as the respective industry would in perfect competition* (Schumpeter 1975: 106, cited by Kamien and Schwartz 1982).

The empirical literature provides us with different results on how the above hypothesis is to be tested. Some of the authors confirm the viewpoint of Schumpeter, while the others reject it. Here, emphasis will be on the literature that declines the validity of the hypothesis.

First of all, from the theoretical point of view, there are three reasons why monopoly power might not be positively related to innovative activity according to Kamien and Schwartz (1982):

1. A firm possessing monopoly power may find additional leisure as being superior to additional profits;

2. Protecting its monopoly position may become much more important for such a firm than acquiring a new one;

3. A firm earning monopoly profits may be slower in replacing its current product or process with a superior one than a firm earning only normal profits or possible entrant.

So, the firm currently holding monopoly power could be less motivated in obtaining additional profits than the firm without a monopoly position. The fact that possession of a monopoly power could discourage a firm from innovative activity was also realized by Schumpeter in his *Business Cycles* (1964):

> *Economic evolution or "progress" would differ substantially from the picture we are about to draw, if that form (Trustified Capitalism), of organization prevailed throughout the economic organism. Giant concerns still have to react to each other's innovations, of course, but they do so in other and less predictable ways than firms which are drops in a competitive sea,...*

> *Even in the world of giantfirms, new ones rise and others fall into the background. Innovations still emerge primarily with the "young" ones, and the "old" ones display as a rule symptoms of what is euphemistically called conservatism* (Schumpeter 1964: 71, cited by Kamien and Schwartz 1982).

Evidence in the empirical literature on the rejection of Schumpeter's hypothesis follows.

In his work Stigler (1956) observed fourteen highly concentrated industries, and eight industries in which concentration was low. He compared the rate of technical progress in those industries. The rate was measured by the decrease in labor requirements. The main finding was that the biggest advance was made in industries where concentration was decreasing rapidly, while in industries where concentration stayed on high level advancement was the smallest. Stigler concluded that an increase in competition in an industry encourages technical advance.

Mansfield (1963) states that "*although an industry's market structure is but one of many factors influencing the rate of technical progress, it is important in formulating public policy that we learn more about the direction and magnitude of its effects* (Mansfield 1963: 574)". He observed that in coal and petroleum industries the largest four firms' share of the innovations was greater than their market share, but for steel industry the result was opposite. He concluded that the validity of the Scumpeterian hypothesis depends on the industry observed. Moreover, he stated that the suitable environment for technological progress was pure competition, since under such conditions a firm was forced to seek out new ideas and apply them.

In his study, Williamson (1965) set the hypothesis that "*the relative innovative performance of the largest firms may decline as monopoly power increases* (Williamson 1965: 68)". He argued that the ratio between share of the innovations introduced by four largest firms in an industry and their market share should vary inversely with monopoly power, since the largest firms could neglect the behavior of their rivals due to monopoly advantages in the short run, and restrain innovation by preserving stable interfirm relations among the principle rivals in the long run. Using the data from the work of Mansfield, Williamson established the result that the four largest firms in an industry contributed less innovations than their market share for the concentration ratio above 30-50%.

In his paper, Shrieves (1978) found several results. First, the relationship between R&D intensity and concentration depends on the type of product produced in an industry. Among the producers of durable goods, this relationship is significantly negative. Second, he found that in concentrated industries the largest firms innovate proportionally less than the smaller ones. Shrieves concluded that "*high concentration levels may have an adverse effect on innovative effort in some industries (...). This finding admits the possibility that the theoretical view which opposes Schumpeter's is the more relevant theory for some industries or technologies* (Shrieves 1978: 342)".

Adams (1970) compared the R&D-spending intensity and the four-firm concentration index by industries in the United States. His finding was that for the high technology industries, the larger concentration index implied smaller R&D-spending intensity. Therefore, he rejected the hypothesis that there exists a positive relation between seller concentration and research activity.

In his study, Globerman (1973) used data on Canadian manufacturing industries in order to examine the influences of concentration and technological opportunity on research effort. Regressing R&D personnel per one thousand employees on a four-firm concentration index resulted in highly significant negative coefficient for industries with greater technological opportunity. So, for this particular group of industries, research intensity was inversely related to concentration. For other industries, no significant relationship was detected.

3 Model

The model under consideration represents the extension of the model constructed in Boone (2001). In contrast to it, much more attention is placed on the behavior of R&D laboratory. While in Boone's model the R&D laboratory provides new technology exogenously, here it solves the problem of maximizing its own profit, and, based on that, decides how much improved technology to offer to the firms.

So, there are two parties in this model. On the one hand, there is a R&D laboratory that works on process innovations. By maximizing its own profits, it determines how big improvement on the current best technology it will offer to the firms. On the other hand, there are firms that compete one against the others in the product market, earn profits (or leave the market if they earn zero profits[1]) and decide whether to acquire the new technology that is offered or not.

All current technologies used by firms are represented by a sequence of constant marginal cost levels $(c_1, c_2, c_3, \ldots)$ such that $c_1 \leq c_2 \leq c_3 \leq \ldots$[2]. Firm i uses the technology with marginal cost of c_i. All firms that are active have different marginal costs, with firm 1 being the leader, and all the potential entrants have marginal costs $c_i = +\infty$, by convention. The leader always makes positive profits by the assumptions made on the profit function[3]. Boone (2001) introduces a parameter $\theta \in \Theta = \mathbb{R}_+$, that represents the intensity of competition among the firms. For the purpose of completeness and clarity, the definition of the parameter θ will be stated here.

Definition 3.1. (Boone 2001: 712) A parameter $\theta \in \mathbb{R}_+$ is said to measure the intensity of competition, with competition becoming more intense as θ rises, if

(a) *local monopoly*: $\lim_{\theta \downarrow 0} \pi_i(c_i, c_{-i}; \theta) - \pi_i(c_i, c'_{-i}; \theta) = 0$ for each (c_i, c_{-i}) and (c_i, c'_{-i}) in C;

(b) *the least efficient firm in the market loses as competition becomes more intense*: for given $c \in C^0$ and $\theta \in \mathbb{R}_+$, let n denote the least efficient firm active in the market, that is $\pi_n(c; \theta) > 0$ with $\pi_{n+1}(c; \theta) = 0$, then $\pi_n(c; \theta)$ is decreasing in θ, further, for each $i = 2, 3, 4, \ldots$ there exists a value θ_i such that $\pi_i(c; \theta) = 0$ for each $\theta \geq \theta_i$;

(c) *if the leader is far enough ahead, he gains as competition becomes more intense*: for each $c_{-1} \in C$ with $c_2 > 0$ there exists $c_1^+ \in [0, c_2]$ and $\theta^+ \geq 0$ such that $\pi_1(c_1, c_{-1}; \theta)$ is nondecreasing in θ for each $c_1 \in [0, c_1^+]$ and $\theta > \theta^+$

(d) *if all active firms have similar costs, they all lose if competition becomes more intense*: for given $c \in C$ and $\theta \in \mathbb{R}_+$, let n denote the least efficient firm in the market then there exists $\epsilon > 0$ such that $max_{1 \leq i,j \leq n} |c_i - c_j| = c_n - c_1 < \epsilon$ implies $\pi_i(c; \theta)$ is decrasing in θ for each $i = 1 \ldots, n$, further if $c_1 = c_2 = \ldots = c_n$ then $\lim_{\theta \to \infty} \pi_i(c; \theta) = 0$ for $i = 1 \ldots, n$.

The R&D laboratory produces a new technology. It does that by exerting effort, which will be called productivity in the model. How much effort it will exert depends on the intensity of competition, as stated in the following definition.

[1] This is introduced as a convention in Boone (2001).

[2] All possible current technologies $(c_1, c_2, c_3, \ldots)$ fulfilling $c_1 \leq c_2 \leq c_3 \leq \ldots$ constitute a set C.

[3] For the assumptions on the profit function, $\pi_i(c; \theta)$, see Boone (2001: 711). Also, if the leader earns positive profits and $c_1 < c_2 < c_3 < \ldots$ holds instead of $c_1 \leq c_2 \leq c_3 \leq \ldots$, set containing sequences of all possible technologies is denoted C^0.

Definition 3.2. (Productivity) Productivity of the R&D laboratory is a function $\kappa : \Theta \to [1, +\infty]$.

Since the relationship between technological progress (i.e. how far new technology from the current best is) and the intensity of competition is of interest, productivity of R&D is defined to depend on θ. The relationship between exerted effort and new technology is defined as follows.

Definition 3.3. (New technology) A new technology, which is represented by a constant marginal costs c_0, is related to the productivity of the R&D laboratory in the following manner:

$$c_0 = \frac{1}{\kappa(\theta)} c_1 \tag{1}$$

where c_1 denotes the current best technology.

Therefore, with making a decision how productive to be, the R&D laboratory determines how big an improvement on the current best technology will be. The decision on productivity is made by maximizing the profits from selling the innovation. Once $\kappa(\theta)$ is determined, the amount of technological progress can be backed out from (1). κ is defined to have range in the interval $[1, +\infty]$, in order the innovation to be progressive (i.e. $c_0 \leq c_1$).

A new technology is considered to be a patent, i.e. only one firm at a time can acquire it. Therefore, the R&D laboratory sells the innovation on the basis of auction, namely, a firm that values the innovation most will be the buyer. Since the R&D laboratory can observe current technologies and intensity of competition in the market, because those are assumed to be common knowledge, it can determine exactly which firm will be willing to offer the highest price for the new technology. Therefore, it maximizes profits having in mind which firm will be the buyer of the process innovation.

To clarify how the model works, the order of the events will be summarized here:

1. The R&D laboratory observes what the current technologies used by the firms in the market are $(c_1, c_2, \ldots)$, and what the intensity of competition in the market is (θ).

2. Based on this information, the R&D laboratory determines which firm will be the innovator, i.e. which firm will have the highest valuation of a new technology.

3. The R&D laboratory decides how productive it should be (and, consequently, how much improved the current best technology will be) in order to maximize profits from selling the innovation.

In order to be able to write down the problem of the innovator, two constructs are needed: first, how firms value the innovation, and second, what the costs of the R&D laboratory from innovating are. Firm i's valuation, denoted by $\Delta\pi_i$, is defined as the difference in its profits if it is the one that acquires the new technology and if some other firm buys the innovation. Since profits depend on the intensity of competition, the valuation also depends on θ. In addition to that, since c_0 influences profits and is determined endogenously here (in contrast to Boone's model), profits also depend on the productivity κ. So, firm i's valuation of the innovation can be written as[4]:

[4]This is a bit redefined expression compared to the one defined in Boone (2001), since now valuation depends on κ as well.

$$\Delta\pi_i(\theta;\kappa) = \pi_i(c_0, c_{-i};\theta) - \pi_i(c_i, c_0^j, c_{-i-j};\theta)$$

where $\pi_i(c_0, c_{-i};\theta)$ is the profit of firm i if it is the one that acquires the new technology, $\pi_i(c_i, c_0^j, c_{-i-j};\theta)^5$ is the profit of firm i if firm j is the one that buys the innovation, and $c_0 = (1/\kappa)c_1$. To put some more structure on how firms' valuations of the innovation behaves as κ changes, the following assumption is introduced:

Assumption 3.4. Firm i's valuation of the innovation $\Delta\pi_i(\theta;\kappa)$ satisfies:

(a) $\frac{\partial\Delta\pi_i(\theta;\kappa)}{\partial\kappa} > 0$

(b) $\frac{\partial^2\Delta\pi_i(\theta;\kappa)}{\partial\kappa^2} < 0$

Condition (a) states that higher productivity (lower c_0) increases the valuation, for θ being held constant. This is so, since the profits of the firm are decreasing in its own cost, and they are nondecreasing in opponents' costs. Condition (b) says that the increase of the valuation slows down as productivity rises. This is because a slight increase in productivity decreases c_0 more when κ is small than when κ is large.

Definition 3.5. The costs of the R&D laboratory from exerting effort, denoted by v, are represented by a function $v : [1, +\infty] \rightarrow [0, +\infty]$.

On the other hand, the costs of the R&D laboratory from innovating depend on its own productivity, and not on the intensity of competition (or, to be more precise, depend indirectly on θ, since the intensity of competition influences productivity). The assumption put on the costs of the R&D laboratory is that they depend linearly on the productivity. Also, having productivity $\kappa(\theta) = 1$ incurs no costs for the laboratory, since a technology $c_0 = c_1$ has already been produced, so $v(1) = 0$.

Putting both constructs together, the problem that the R&D laboratory solves reads as follows:

$$\max_{\kappa} \Delta\pi_i(\theta;\kappa) - v(\kappa) \tag{2}$$

where i denotes the firm that will buy the innovation.

[5] c_{-i} is a sequence of technologies without marginal costs of firm i. c_{-i-j} denotes the sequence of marginal costs omitting those of firms i and j.

4 Results

In this section, the results will be obtained for a model with two firms on the market, the leader and the follower, and the R&D laboratory.

In his paper, Boone (2001) forms the difference of valuations, $\Delta\pi_1(\theta) - \Delta\pi_2(\theta)$. He shows that this difference can be written as a sum of four effects. This way of rewriting will be reproduced here, reformulating the four effects in order to include the productivity of the R&D laboratory:[6]

$$\begin{aligned}\Delta\pi_1(\theta;\kappa) - \Delta\pi_2(\theta;\kappa) &= [\pi_1(\frac{1}{\kappa}c_1, c_2; \theta) - \pi_1(c_1, \frac{1}{\kappa}c_1; \theta)] \\ &\quad - [\pi_2(c_1, \frac{1}{\kappa}c_1; \theta) - \pi_2(\frac{1}{\kappa}c_1, c_2; \theta)] \\ &= BRL + BCF + BCU - CU\end{aligned}$$

where

$$\begin{aligned}BRL =& [\pi_1(\frac{1}{\kappa}c_1, c_2; \theta) - \pi_1(c_1, c_2; \theta)] - [\pi_1(\frac{1}{\kappa}c_1, c_1; \theta) - \pi_1(c_1, c_1; \theta)] \\ BCF =& [\pi_2(c_1, c_1; \theta) - \pi_2(\frac{1}{\kappa}c_1, c_1; \theta)] - [\pi_2(c_1, c_2; \theta) - \pi_2(\frac{1}{\kappa}c_1, c_2; \theta)] \\ BCU =& \pi_1(c_1, c_2; \theta) - \pi_1(c_1, c_1; \theta) \\ CU =& \pi_2(c_1, c_1; \theta) - \pi_2(c_1, c_2; \theta)\end{aligned}$$

Although reformulated, these four effects have the same interpretation as in Boone (2001). The meaning of the four effects is the following:

> *The Being a Remote Leader [BRL] effect [states that] (...) it is more profitable to innovate when your follower is remote than when he is close. The Being a Close Follower [BCF] effect [says that] (...) you lose more when your opponent innovates as you are closer. The Being Caught Up [BCU] effect tells us that the leader is willing to pay to avoid the follower coming alongside. (...) The Catching Up [CU] effect (...) says that firm 2 is willing to pay to catch up with firm 1* (Boone 2001: 717).

Boone (2001) shows that all four effects are positive for $\theta > 0$[7], and $\lim_{\theta\downarrow 0} BRL + BCF + BCU = 0$ and $\lim_{\theta\to+\infty} CU = 0$[8]. He also shows that "*there exist $\theta^l, \theta^f \in \mathbb{R}_+$ such that for each $\theta > \theta^l$ the leader increases its dominance (...); for each $\theta < \theta^f$ the follower leapfrogs* (Boone 2001: 718)". So, for θ high enough $\Delta\pi_1(\theta;\kappa) - \Delta\pi_2(\theta;\kappa)$ is positive, and when the intensity of competition is low (θ close to zero) this difference is negative. From this he concludes that with high intensity of competition ($\theta > \theta^l$) the leader will be the one who buys the innovation, while with low θ ($\theta < \theta^f$) the follower acquires the new technology.[9]

These four effects can now be used to prove the existence of the solution in (2).

Proposition 4.1. The solution in (2) exists in a case of duopoly.

[6]For the original definition of the four effects see (Boone 2001: 716).
[7]See Lemma 3.1. in Boone (2001: 717).
[8]See Proposition 3.2. in Boone (2001: 717).
[9]For the exact result, see Theorem 3.3. in Boone (2001: 718).

Proof. As stated above, the CU effect dominates and is positive when the intensity of competition is weak. Therefore, $\Delta\pi_2(\theta;\kappa)$ is positive for every possible κ. In particular, for $\kappa = 1$, $\Delta\pi_2(\theta;1) - v(1) > 0$ holds. If θ is high enough, CU effect is dominated, i.e. $BRL + BCF + BCU > CU$. But BCU shows leader's willingness to pay not to have the follower alongside. Therefore, $\Delta\pi_1(\theta;1) - v(1) > 0$. This proves the existence of the solution in a case of duopoly. □

It is worth noting how the profit functions of the firms react to changes in productivity if the firm is the one that buys the innovation, and if not.

Remark 4.2. For the profit functions of the leader the following two statements hold:

(i) $\frac{\partial\pi_1(\frac{1}{\kappa}c_1,c_2;\theta)}{\partial\kappa} > 0$ when he acquires a new technology;

(ii) $\frac{\partial\pi_1(c_1,\frac{1}{\kappa}c_1;\theta)}{\partial\kappa} < 0$ when the follower buys the innovation.

Proof. For part (i) the expression of interest can be rewritten as:

$$\begin{aligned}\frac{\partial\pi_1(\frac{1}{\kappa}c_1,c_2;\theta)}{\partial\kappa} &= \frac{\partial\pi_1(\frac{1}{\kappa}c_1,c_2;\theta)}{\partial c_0}\frac{\partial c_0}{\partial\kappa}\\ &= -\frac{\partial\pi_1(\frac{1}{\kappa}c_1,c_2;\theta)}{\partial c_0}\frac{1}{\kappa^2}c_1\end{aligned}$$

Since profits of the firm are decreasing in its own costs, the result follows.

A similar way of rewriting expression in (ii) can be employed in order to obtain:

$$\begin{aligned}\frac{\partial\pi_1(c_1,\frac{1}{\kappa}c_1;\theta)}{\partial\kappa} &= \frac{\partial\pi_1(c_1,\frac{1}{\kappa}c_1;\theta)}{\partial c_0}\frac{\partial c_0}{\partial\kappa}\\ &= -\frac{\partial\pi_1(c_1,\frac{1}{\kappa}c_1;\theta)}{\partial c_0}\frac{1}{\kappa^2}c_1\end{aligned}$$

Remember that the profits of the firm are increasing in the opponent's costs. □

The same results can be obtained for the profit function of the follower. These can be used in deriving the further result on how the four effects react to productivity increase.

Lemma 4.3. BRL and BCF are increasing in productivity, while BCU and CU does not change with κ.

Proof. Taking a derivative with respect to κ of BRL gives the following expression:

$$\frac{\partial\pi_1(\frac{1}{\kappa}c_1,c_2;\theta)}{\partial\kappa} - \frac{\partial\pi_1(\frac{1}{\kappa}c_1,c_1;\theta)}{\partial\kappa}$$

Both terms in the expression above are positive (by Remark 4.2.), but since it pays more to the leader to innovate when the follower is further away the first term is greater. It follows that $(\partial BRL)/(\partial\kappa) > 0$.

Doing the same thing with BCF, the following expression is obtained:

$$\frac{\partial\pi_2(\frac{1}{\kappa}c_1,c_2;\theta)}{\partial\kappa} - \frac{\partial\pi_2(\frac{1}{\kappa}c_1,c_1;\theta)}{\partial\kappa}$$

Both terms here are negative, but since the close follower loses more when the leader innovates the second term is greater in absolute values. Therefore, $(\partial BCF)/(\partial \kappa) > 0$.

Since BCU and CU does not depend on productivity, derivatives of these two with respect to κ equal zero. $\square$

Now, attention will be placed on investigating the behavior of firms' valuations to the innovation. First, the behavior of the leader's valuation will be examined.

Lemma 4.4. For $\theta', \theta" \in \mathbb{R}_+$ such that $\theta^l < \theta' < \theta"$, $\Delta\pi_1(\theta'; \kappa) < \Delta\pi_1(\theta"; \kappa)$ for any given κ. Furthermore, the difference $\Delta\pi_1(\theta"; \kappa) - \Delta\pi_1(\theta'; \kappa)$ is increasing in κ.

Proof. To prove the first part, the difference $\Delta\pi_1(\theta"; \kappa) - \Delta\pi_1(\theta'; \kappa)$ is reformulated as:

$$\left[\pi_1(\frac{1}{\kappa}c_1, c_2; \theta") - \pi_1(\frac{1}{\kappa}c_1, c_2; \theta')\right] + \left[\pi_1(c_1, \frac{1}{\kappa}c_1; \theta') - \pi_1(c_1, \frac{1}{\kappa}c_1; \theta")\right]$$

The term in the first square brackets is positive (by Definition 3.1.(c)), as well as the other term (by Definition 3.1.(b)). Taking a derivative with respect to κ of this difference results in:

$$\left[\frac{\partial\pi_1(\frac{1}{\kappa}c_1, c_2; \theta")}{\partial\kappa} - \frac{\partial\pi_1(\frac{1}{\kappa}c_1, c_2; \theta')}{\partial\kappa}\right] + \left[\frac{\partial\pi_1(c_1, \frac{1}{\kappa}c_1; \theta')}{\partial\kappa} - \frac{c_1, \partial\pi_1(\frac{1}{\kappa}c_1; \theta")}{\partial\kappa}\right]$$

Since the profits are decreasing in firm's own costs and the leader enjoys higher profits when the intensity of competition increases, the term in the first square brackets is positive. Since the leader loses more from being leapfrogged as θ increases and his profits decrease more the more the follower innovates, the second term is also positive. $\square$

Actually, what Lemma 4.4. asserts is that the mixed derivative of $\Delta\pi_1(\theta; \kappa)$ is positive, i.e. $(\partial^2\Delta\pi_1(\theta; \kappa))/(\partial\kappa\partial\theta) > 0$ for $\theta > \theta^l$. The following lemma is similar, but concerned with the follower.

Lemma 4.5. For $\theta'.\theta" \in \mathbb{R}_+$ such that $\theta' < \theta" < \theta^f$, $\Delta\pi_2(\theta'; \kappa) > \Delta\pi_2(\theta"; \kappa)$ for any given κ. Furthermore, the difference $\Delta\pi_2(\theta'; \kappa) - \Delta\pi_2(\theta"; \kappa)$ is increasing in κ.

Proof. Again for proving the first part, the difference $\Delta\pi_2(\theta'; \kappa) - \Delta\pi_2(\theta"; \kappa)$ is reformulated as:

$$\left[\pi_2(c_1, \frac{1}{\kappa}c_1; \theta') - \pi_2(c_1, \frac{1}{\kappa}c_1; \theta")\right] + \left[\pi_2(\frac{1}{\kappa}c_1, c_2; \theta") - \pi_2(\frac{1}{\kappa}c_1, c_2; \theta')\right]$$

The term in the first square brackets is positive since innovating pays more for the follower when strategic effects are low, while the other term is positive because the follower loses more if he does not innovate when the intensity of competition is weak. Taking a derivative with respect to κ of this difference gives the following expression:

$$\left[\frac{\partial\pi_2(c_1, \frac{1}{\kappa}c_1; \theta')}{\partial\kappa} - \frac{\partial\pi_2(c_1, \frac{1}{\kappa}c_1; \theta")}{\partial\kappa}\right] + \left[\frac{\partial\pi_2(\frac{1}{\kappa}c_1, c_2; \theta")}{\partial\kappa} - \frac{c_1, \partial\pi_2(\frac{1}{\kappa}c_1, c_2; \theta')}{\partial\kappa}\right]$$

Because innovating for the follower is more fruitful when the intensity of competition is weak and firm's profits are increasing in productivity of the R&D laboratory, the term in the first square brackets is positive. The term in the second square brackets is also positive, since the follower loses even more because his profits are increasing in leader's costs. □

By Lemma 4.5., $(\partial^2 \Delta\pi_2(\theta;\kappa)/(\partial\kappa\partial\theta) < 0$ for $\theta < \theta^f$.

One more auxiliary result, which will be needed later on, is to be stated.

Lemma 4.6. For $\theta" > \theta^l$ and $\theta' < \theta^f$, the difference $\Delta\pi_2(\theta";\kappa) - \Delta\pi_2(\theta';\kappa)$ is increasing in κ.

Instead of a rigorous proof, the intuition why the result should hold will be provided here:

Differentiating $\Delta\pi_2(\theta";\kappa) - \Delta\pi_2(\theta';\kappa)$ with respect to κ results in:

$$\left[\frac{\partial\pi_2(c_1, \frac{1}{\kappa}c_1; \theta")}{\partial\kappa} - \frac{\partial\pi_2(c_1, \frac{1}{\kappa}c_1; \theta')}{\partial\kappa}\right] + \left[\frac{\partial\pi_2(\frac{1}{\kappa}c_1, c_2; \theta')}{\partial\kappa} - \frac{c_1, \partial\pi_2(\frac{1}{\kappa}c_1, c_2; \theta")}{\partial\kappa}\right]$$

For the follower, innovating in the competitive market increases profits much faster compared to the situation where the intensity of competition is low. Thus, the term in the first square brackets should be positive. On the other hand, the follower loses more if he stays behind in case when the intensity of competition is strong. For this reason, the other term in the upper equation is positive. Therefore, the difference $\Delta\pi_2(\theta";\kappa) - \Delta\pi_2(\theta';\kappa)$ is increasing in κ.

Finally, the following result shows how productivity reacts to changes in the intensity of competition.

Theorem 4.7. For $\theta < \theta^f$, $\frac{\partial\kappa}{\partial\theta} < 0$, while for θ high enough, i.e. $\theta > \theta^l$, $\frac{\partial\kappa}{\partial\theta} > 0$. Moreover, for $\theta > \theta^l$ productivity of the R&D laboratory $[\kappa(\theta)]$ is high, while for $\theta < \theta^f$, $\kappa(\theta)$ is low.

Proof. First, for $\theta < \theta^f$ it has been shown that the follower buys the innovation. Hence, the problem of the R&D laboratory translates into:

$$\max_{\kappa} \Delta\pi_2(\theta;\kappa) - v(\kappa)$$

Then the FOC reads as follows:

$$\frac{\partial\Delta\pi_2(\theta;\kappa)}{\partial\kappa} = \frac{\partial v(\kappa)}{\partial\kappa} \tag{3}$$

Since the left hand side of the FOC is strictly decreasing (by Assumption 3.4.(b)), and the right hand side is constant (by assumption of v being linear in κ), equation (3) implicitly defines optimal productivity for R&D laboratory. Because FOC is of the form $F(x, y) = c$, the implicit function theorem can be used in order to obtain the following expression:

$$\frac{d\kappa}{d\theta} = -\frac{\frac{\partial^2\Delta\pi_2(\theta;\kappa)}{\partial\kappa\partial\theta}}{\frac{\partial^2\Delta\pi_2(\theta;\kappa)}{\partial\kappa^2}}$$

The numerator of the expression above is negative (by Lemma 4.5.), as well as the denominator (by Assumption 3.4.(b)). Therefore, $(\partial\kappa/\partial\theta) < 0$ holds for $\theta < \theta^f$

Now, consider the case when $\theta > \theta^l$. The leader is the one who acquires a new technology. The FOC can be derived in a similar fashion:

$$\frac{\partial\Delta\pi_1(\theta;\kappa)}{\partial\kappa} = \frac{\partial v(\kappa)}{\partial\kappa} \tag{4}$$

Equilibrium productivity is defined implicitly by equation (4). Using the implicit function theorem, an expression for $(\partial\kappa/\partial\theta)$ can be obtained:

$$\frac{d\kappa}{d\theta} = -\frac{\frac{\partial^2\Delta\pi_1(\theta;\kappa)}{\partial\kappa\partial\theta}}{\frac{\partial^2\Delta\pi_1(\theta;\kappa)}{\partial\kappa^2}}$$

The expression remains the same as in the previous case, but the result changes. By Lemma 4.4. the numerator alternates the sign and becomes positive, while the denominator stays negative (by Assumption 3.4.(b)). Thus, for $\theta > \theta^l$, $(\partial\kappa/\partial\theta) > 0$ holds.

For proving the second part, it has to be shown that, for any κ, $\frac{\partial\Delta\pi_1(\theta";\kappa)}{\partial\kappa}$ is greater than $\frac{\partial\Delta\pi_2(\theta';\kappa)}{\partial\kappa}$, where $\theta" > \theta^l$ and $\theta' > \theta^f$. For this purpose, the reaction of the difference $\Delta\pi_1(\theta";\kappa) - \Delta\pi_2(\theta';\kappa)$ to changes in productivity has to be observed. The difference can be rewritten as:

$$\begin{aligned}\Delta\pi_1(\theta";\kappa) - \Delta\pi_2(\theta';\kappa) =& [\Delta\pi_1(\theta";\kappa) - \Delta\pi_2(\theta";\kappa)] \\ &+ [\Delta\pi_2(\theta";\kappa) - \Delta\pi_2(\theta';\kappa)]\end{aligned}$$

Differentiating the above expression with respect to κ gives:

$$\begin{aligned}\frac{\partial[\Delta\pi_1(\theta";\kappa) - \Delta\pi_2(\theta';\kappa)]}{\partial\kappa} =& \frac{\partial[\Delta\pi_1(\theta";\kappa) - \Delta\pi_2(\theta";\kappa)]}{\partial\kappa} \\ &+ \left[\frac{\Delta\pi_2(\theta";\kappa)}{\partial\kappa} - \frac{\Delta\pi_2(\theta';\kappa)}{\partial\kappa}\right]\end{aligned}$$

By Lemma 4.3. the first term on the right hand side is positive. Also, the term in square brackets is positive (by Lemma 4.6.). This proves the second part of the theorem. □

So, the theorem above establishes the relationship between intensity of competition and the level of technological progress. It shows that this relationship is non-monotone. Furthermore, it determines that improvements on the current best technology are higher when competition is more intense.

With weak intensity of competition (θ low), there is no strategic interaction between the firms in the market. Each firm takes care of its own profits. The follower is very interested in acquiring a better technology (has a higher valuation than the leader) that will have a big impact on its profits. The R&D laboratory can observe this and offers a slightly improved technology to this firm. Consequently, with weak intensity of competition technological improvements will be small, which is in line with the findings in Theorem 4.7.

On the other hand, when the intensity of competition is strong (θ high), each firm's decisions have strong effects on the other. In this setting, the leader wants to escape from this severe competition, and does this by acquiring a new technology. The R&D

laboratory maximizes its profits, and the high valuation of the leader leads to its high productivity. Thus, with strong intensity of competition technological progress will be high.

5 An illustration of the results

In this section, results previously obtained will be illustrated by an example. Actually, it will be even shown that the results hold in the case of three firms (at least in this particular setting). This is an extension of a three-firm example from Boone (2001).

The setup is the following. There are three firms in the market, each with associated constant marginal costs c_i for $i = 1, 2, 3$, where $c_1 < c_2 < c_3$. They are producing and selling a good to consumers, who have traveling costs, denoted by t, for reaching the firm in order to buy the good. Very high t means that it is quite expensive for a consumer to travel, so he would choose the nearest firm to purchase the product. In this case, firms possess a local monopoly and competition among them is weak. On the other hand, with t being low, competition among firms is quite severe. For this reason, an inverse of the traveling costs $1/t$ can be considered as a measure of the intensity of competition ($\theta = 1/t$).

Each firm charges a price p_i, and faces a demand function $D_i(p_1, p_2, p_3; t) = (2t + \sum_{j \neq i} p_j - 2p_i)/(2t)$, for $i = 1, 2, 3$. Firms choose p_i in order to maximize their own profits. Nash equilibrium profits have the following form $\pi_i(c_1, c_2, c_3; t) = (5t + \sum_{j \neq i} c_j - 2c_i)^2/(25t)$, $i = 1, 2, 3$.

For $t \in [4, 10]$, i.e. $\theta \in [1/10, 1/4]$, and $(c_1, c_2, c_3) = (2, 4, 8)$, Boone (2001) shows the innovator will be either firm 2 or firm 3. The intuition behind this is that for such a weak intensity of competition ($\theta \leq 1/4$) the strategic effects among the firms are so low that firm 1 does not want to innovate, because its profits are (almost) not affected by the behavior of the other two firms and it already has quite low marginal costs ($c_1 = 2$). Therefore, only firms 2 and 3 are interested in acquiring new technology. Their valuations of the innovation are the following:

$$\Delta\pi_2(t, \kappa) = \pi_2(2, 2/\kappa, 8; t) - \pi_2(2, 4, 2/\kappa; t)$$
$$\Delta\pi_3(t, \kappa) = \pi_3(2, 4, 2/\kappa; t) - \pi_2(2, 2/\kappa, 8; t)$$

After taking the difference between the valuations, it can be calculated what is a critical value for t, namely what is the value of the traveling costs for which the sign of $\Delta\pi_2(t, \kappa) - \Delta\pi_3(t, \kappa)$ changes. Of course, this value will depend on κ. From the following graph it can be seen that, for $\kappa = 1.6$, the difference between the valuations is positive for $t < 4.6$, and negative otherwise (see Figure 1). This means that for $\theta \in [1/4.6, 1/4]$ firm 2 will buy the innovation, while for $\theta \in [1/10, 1/4.6]$ firm 3 will be the one that acquires a new technology.

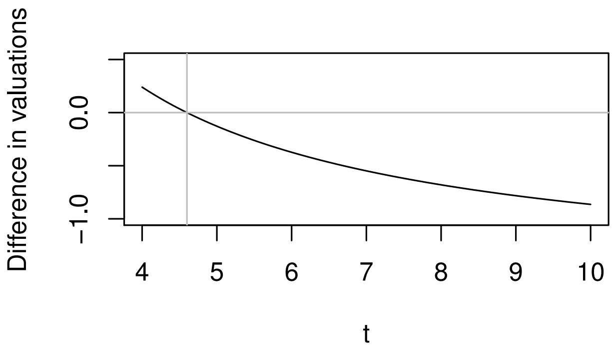

Figure 1: Difference $\Delta\pi_2(t,\kappa) - \Delta\pi_3(t,\kappa)$ for $\kappa = 1.6$

Source: My computations

On the other hand, there is an R&D laboratory that solves its own profit maximization problem. For simplification, its costs from exerting effort will be specified as $v(\kappa) = \kappa - 1$, which satisfies the assumptions placed on costs of R&D laboratory (linear in productivity, and $v(1) = 0$).

When the firm 2 is the one that acquires a new technology, the R&D laboratory solves the following problem:

$$\max_\kappa \pi_2(2, 2/\kappa, 8; t) - \pi_2(2, 4, 2/\kappa; t) - (\kappa - 1)$$

It is easy to show that the first order condition takes the following form:

$$25\kappa^3 - (60 + \tfrac{56}{t})\kappa + \tfrac{24}{t} = 0$$

This FOC has the form of $F(\kappa, \theta) = 0$[10]. Therefore, the implicit function theorem can be used to obtain the expression for $d\kappa/d\theta$.

$$\tfrac{d\kappa}{d\theta} = \tfrac{56\kappa - 24}{75\kappa^2 - 60 + 56\theta}$$

Since $\kappa \geq 1$ the numerator is always positive. For the same reason, the denominator is positive $\forall\theta \in [1/10, 1/4]$. Therefore, $\frac{d\kappa}{d\theta} > 0$ in this case, which confirms the results from the previous section for the case when the more efficient firm buys the innovation.

By a similar procedure[11], an expression for $d\kappa/d\theta$ can be obtained in the case when the firm 3 is the one to acquire a new technology from the R&D laboratory. This expression has the following form:

$$\tfrac{d\kappa}{d\theta} = -\tfrac{8\kappa + 24}{75\kappa^2 - 60 + 8\theta}$$

Again, the numerator is positive since $\kappa \geq 1$. Together with the denominator being positive $\forall\theta \in [1/10, 1/4]$, in this case the sign of $d\kappa/d\theta$ is negative. This is in line with the results when the least efficient firm is the one that innovates.

Further, it can be shown that the average productivity of the R&D laboratory, when firm 2 is the one that buys the innovation, is 1.67. This translates into 41%

[10] remember that $\theta = 1/t$.

[11] The only difference is that here, R&D laboratory solves the following problem $\max_\kappa \pi_3(2, 4, 2/\kappa; t) - \pi_2(2, 2/\kappa, 8; t) - (\kappa - 1)$.

improvement on the current best technology. On the other hand, when firm 3 acquires the innovation, average productivity is 1.53. This means that the technological progress is approximately 34%. All this confirms the result that, with higher intensity of competition, technological improvements are bigger steps forward.

Results described above are depicted in Figure 2.

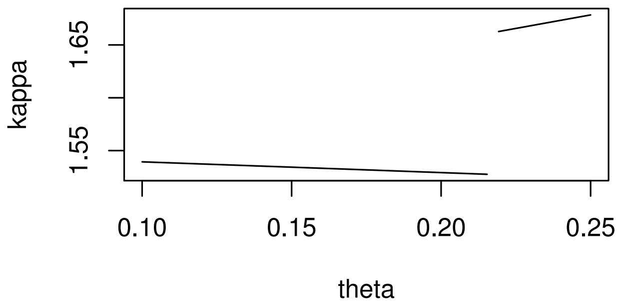

Figure 2: Productivity as a function of the intensity of competition

Source: My computations

6 Conclusion

In the paper the relationship between intensity of competition and level of technological progress has been analysed. The empirical phenomenon to be captured was that in monopolized markets technological improvements are small compared to competitive markets. In a simple environment without many restrictions on the behavior of firms and the R&D laboratory, this has been achieved.

The main result of the paper shows two things. First, when the intensity of competition is weak innovations are represented by small improvements of the current best technology, while for the case when competition is strong technological advancements are large. Second, it has been shown that the intensity of competition influences technological progress in a non-monotone way.

The next step in an examination of this question would be to introduce a stochastic relationship between the productivity of the R&D laboratory and the new technology. This might be an interesting way to go in extending the current model.

References

[1] Adams William J. (1970): *Firm Size and Research Activity: France and the United States.* Quarterly Journal of Economics, Vol. 84, No. 3, pp. 386-409.

[2] Boone Jan (2001): *Intensity of competition and the incentive to innovate.* International Journal of Industrial Organization, Vol. 19, No. 5, pp. 705-726.

[3] Dasgupta Partha and Stiglitz Joseph (1980a): *Uncertainty, Industrial Structure, and the Speed of R&D.* Bell Journal of Economics, Vol. 11, No. 1, pp. 1-28.

[4] Dasgupta Partha and Stiglitz Joseph (1980b): *Industrial Structure and the Nature of Innovative Activity.* The Economic Journal, Vol. 90, No. 358, pp. 266-293.

[5] Globerman Steven (1973): *Market Structure and R&D in Canadian Manufacturing Industries.* Quarterly Review of Economics and Business, Vol. 13, No. 1, pp. 59-67.

[6] Kamien Morton I. and Schwartz Nancy L. (1982) *Market structure and innovation.* Cambridge University Press.

[7] Lee Tom and Wilde Louis L. (1980): *Market Structure and Innovation: A Reformulation.* Quarterly Journal of Economics, Vol. 94, No. 2, pp. 429-436.

[8] Loury Glenn C. (1979): *Market Structure and Innovation.* Quarterly Journal of Economics, Vol. 93, No. 3, pp. 395-410.

[9] Mansfield Edwin (1963): *Size of Firm, Market Structure, and Innovation.* Journal of Political Economy, Vol. 71, No. 6, pp. 556-576.

[10] Schumpeter Joseph A. (1964) *Business Cycles.* McGraw-Hill, New York.

[11] Schumpeter Joseph A. (1975) *Capitalism, Socialism and Democracy.* Harper Colophon Ed., Harper & Row, New York.

[12] Shrieves Ronald E. (1978): *Market Structure and Innovation: A New Perspective.* The Journal of Industrial Economics, Vol. 26, No. 4, pp. 329-347.

[13] Stigler George J. (1956): *Industrial Organization and Economic Progress.* In: L. D. White (ed.): The State of the Social Sciences. Chicago: University of Chicago Press, pp. 269-282.

[14] Tirole Jean (1988) *The Theory of Industrial Organization.* MIT Press, Massachusetts.

[15] Williamson Oliver E. (1965): *Innovation and Market Structure.* Journal of Political Economy, Vol. 73, No. 1, pp. 67-73.