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Abstract
This paper investigates the impact of technical progress on the relationship between competition and investment. Using a model of oligopolistic competition with differentiated products in which firms invest to reduce their marginal cost of production (or to improve quality), I find that technical progress, by increasing the size of innovation, defined as the drop in marginal costs (or the increase in quality) obtained for a given investment amount, increases total investment and decreases the level of competition that maximizes investment in the industry. This feature also holds for consumer surplus and welfare. This means that innovative industries maximize consumer surplus and welfare at a lower level of competitive pressure than do less innovative industries. In the model, competition is measured either by the number of competitors or by the degree of horizontal substitutability between offers. The results hold for both measures, subject to a relatively steady industry specific rate of technological change.

Keywords Market structure · Investment · Technical progress · Competition

JEL Classification D21 · D43 · D92 · L13 · O31

1 Introduction

The relationship between competition and investment is a matter of longstanding debate in industrial organization. However, no clear overall conclusions have been reached thus far. Theoretically, Schmutzler (2013) showed that the relationship can go in any direction. These different outcomes depend on the characteristics of the industry in question. Many parameters may matter: market structure, the type of competition, consumer demand, cost patterns, and technical progress. To the best of my knowledge, the specific influence of technical progress

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on this relation has not been thoroughly studied, despite its essential role in dynamic efficiencies and economic growth.

This paper attempts to fill this gap and focuses on the impact of technical progress on the relationship between competition and investment. In the paper, technical progress is understood as the ease to innovate, which is specific to each technology. This specificity of technical progress for each technology has been highlighted by Koh and Magee who have noted a fairly steady rate of technical progress for more than a century in different technologies. This annual rate of technical progress is much higher for information technologies (over 20%) than for energy technologies (approximately 6%) (Koh and Magee (2006); Koh and Magee (2008)). In both cases, the authors find an almost constant rate of technological change that does not vary beyond relatively narrow limits (< 5% for information technologies and < 2.5% for energy). Thus, the technical progress rate is relatively steady for each technology. An industry is based on a mixture of different technologies; therefore, it is reasonable to assume, as long as the technology mix of the industry does not change too much, that technical progress also does not change significantly at the industry level.

This paper shows that these different paces of innovation have a major impact on the relationship between competition and investment and, therefore, on the relationship between competition and consumer surplus or between competition and welfare. Innovation may be either cost-reducing (process innovation) or quality-improving (product innovation). Competition can be measured by either the number of competitors or the degree of horizontal product substitutability. Innovation is made possible through investment. There are several types of cost-reducing or product quality-enhancing investments: spending on R&D, spending on a cheaper new generation of supply materials (to benefit from R&D of the supplier), spending on process improvement, and so on.

Intuitively, one can reason as follows: innovative industries are more adept at innovating than others. They innovate at lower cost. They therefore benefit from a higher potential for technical progress. However, there could be a difference between potential technical progress and effective technical progress (the extension of the technological frontier). This difference occurs when the margin is insufficient to sustain the investment required by technical progress. In this case, an increase in competitive pressure further reduces the margin and thereby reduces investment. Otherwise, an increase in competitive pressure, as expected, increases investment. Consequently, the investment is maximized at the level of competition above which potential technical progress is no longer achieved. Higher potential technical progress requires more investment for its transformation into actual technical progress and, therefore, the level of competition that maximizes investment decreases.

Some observations seem to corroborate this line of reasoning: for example, the merger between two mobile telecommunication operators Hutchison and Orange in Austria in 2013. This merger had different impacts on voice and data traffic. It decreased voice traffic (minutes of communication) and increased data traffic (megabytes). This is meaningful because voice and data technologies do not undergo innovation at the same pace. Voice traffic increased on average by 3.2% per year before the merger (2009–2013) and 0.3% after (2013–2017). Data traffic increased on average by 63% per year before the merger and 70% after.[1] In other words, the merger had a positive impact on the use of data technology, which displays a high innovation pace, and a negative impact on the use of voice technology, which displays a

[1] Figures are computed by the author from data provided by Telecoms market Matrix Western Europe (Analysys Mason 11 January 2019)

much lower innovation pace. The same event, namely, the merger from 4 to 3 mobile operators, which reduced competition in the same manner for voice and data technologies, led to different outcomes based on their technical progress rate. Although it is not possible to distinguish between voice and data investment, traffic growth requires investment, and we can reasonably assume that an acceleration of traffic growth entails an increase in investment, whereas a slowdown entails a decrease in investment. This suggests that the degree of competition (the number of operators) that maximizes investment is lower for data than for voice technologies. Data technology which displays a higher innovation pace than voice technology maximizes investment under lower competitive pressure.

In this paper, using an oligopoly model, I show that an increase in technical progress, by increasing the size of innovation, tends to decrease the degree of competition that maximizes investment at the industry level. These features are illustrated by different versions of the model in which the measure of competition is the number of firms or the degree of horizontal substitutability. As a result, industries experiencing low technical progress are more likely to exhibit an increasing relationship between competition and investment, whereas industries experiencing higher technical progress are more likely to exhibit an inverted U-shaped or decreasing relationship. The higher the technical progress is, the lower the number of competitors or the degree of horizontal substitutability corresponding to the maximum investment.

More precisely, this paper shows that on the one hand, in a symmetric market, a higher degree of technical progress reduces the number of firms for which investment at the industry level is maximized; on the other hand, in an asymmetric market, technical progress reduces the degree of substitutability for which the level of investment is maximal at the industry level.

Moreover, technical progress spurs an innovation race among firms, which tends to amplify competitive pressure. Innovation shifts the technological frontier and increases the efficiency gap between leaders and laggards, reallocating output from less efficient firms to more efficient ones. According to Boone (2008), this is a general feature of more intense competition. Technical progress is thus a dynamic amplifier of competition. Since a rise in technical progress increases competition, it is not surprising that other types of competition, particularly static forms of competition, such as the number of firms or the degree of horizontal substitutability, have to decrease to maintain the optimal level of competition that maximizes investment.

To illustrate the results, this paper provides parametric examples using demand functions in the manner of Shubik and Levitan (1980) or Singh and Vives (1984).

The remainder of the paper is organized as follows: Section 2 is a literature review. Section 3, based on a model derived from Aghion et al. (2014), explains why the level of innovation tends to decrease the level of competition that maximizes innovation. Section 4, using an oligopoly model of competition, shows that the level of competition that maximizes investment decreases with technological opportunity, i.e., a lower cost of innovation. In symmetric markets, competition is measured by the number of competitors, while in asymmetric markets, competition is represented by the degree of horizontal substitutability. In both cases, the size of innovation, or the level of technical progress, reduces the degree of competition that maximizes investment. Section 5 concludes the paper.

2 Literature Review

The economic literature on the relationship between competition and investment (or innovation) has a long history and is well developed. Insofar as innovation requires investment, we can assume in the rest of the paper that the incentives to innovate and the incentives to invest in cost reduction or in quality improvement go hand in hand.

Schumpeter (1942) insisted on the ability of large firms to innovate, which suggests that concentration fosters innovation and that competition thus hampers it. Arrow (1972) showed that competition tends to foster innovation because firms in competitive sectors have more incentives to innovate than a monopolist, whose innovation could cannibalize its own profit. However, Gilbert and Newbery (1982) highlighted that a monopolist could have more incentives to innovate than a firm under competition. Indeed, a monopolist loses more by not investing in innovation than a firm facing competition because the rent of a monopoly is higher than the joint profit of a duopoly.

Aghion et al. (2005) reconcile those two views. They distinguish between two effects, the "Schumpeterian effect," in which competition reduces investment incentives, and the "escape competition effect," in which competition fosters investment. They show that the relationship between competition and investment is governed by these two opposing effects, and they find an inverted U-shaped relationship for the UK's economy.

More precisely, Aghion et al. (2014) develop a model that details the mechanisms underlying the two effects. In the escape competition effect, competition reduces pre-innovation profit, which makes innovation more attractive, whereas in the Schumpeterian effect, competition instead decreases post-innovation profit, which adversely impacts innovation. In their model, both effects coexist; this is the composition effect that is responsible for the inverted U-shaped relationship. For a low initial degree of competition, the escape competition effect prevails, and thus, an increase in competitive pressure increases innovation. For a high enough initial degree of competition, the Schumpeterian effect prevails, and thus, an increase in competitive pressure reduces innovation. With this theory, Aghion et al. (2019) explain the long-term drop in US productivity growth after a short-term burst following the technological breakthrough induced by the 1990s IT wave.Schmutzler (2013) notices that the relationship between competition and investment could take any shape: increasing, decreasing, U-shaped, or inverted U-shaped. Indeed, this depends on the relative influences of the Schumpeterian and escape competition effects. Bergh ll (2016) finds no empirical evidence for an inverted U relationship in the Finnish ICT industry, and the results are sensitive to the choice of variables.

For symmetric markets, Vives (2008) presents a benchmarking analysis of different models in which several examples demonstrate that an increase in technological opportunity leads to more concentrated markets in the free entry regime, which means that technological progress reduces the number of firms such that competition is sustainable. This result may seem counterintuitive, as greater technological opportunity should increase total output and attract more firms, but Tandon (1984) explains this apparent paradox by the fact that technological opportunity entails more investment in cost reductions, which acts as an entry barrier. The latter effect outweighs the former. This increased investment due to technological opportunity, in some manner, strengthens the Schumpeterian effect more than the escape competition effect. This result is consistent with the empirical findings of Kamien and Schwartz (1982). Jeanjean and Houngbonon (2017) empirically demonstrate that for the mobile telecommunication markets, which are characterized by a high level of technical progress, investment per firm decreases with the number of firms, and the investment trend of the industry is ambiguous (it tends to increase in the short run but eventually decreases in the long run). They also report a positive impact of asymmetry on investment. More recently, Ciriani and Jeanjean (2019) highlight an inverted U relationship between the hourly productivity growth rate and the margin rate in the different sectors of the French economy. They point out that the margin rate that maximizes the hourly productivity growth of the sector is significantly and positively correlated with the technical progress rate.

The literature regarding technological diffusion is also useful for understanding the relationship between competition and innovation. In models in this literature, a new technology is announced. The cost of adoption is assumed to decrease over time, and firms choose when to adopt. The earlier they adopt, the earlier they benefit from the new technology, but the higher the adoption cost is. The adoption date is a trade-off between profit growth and the cost of adoption. Reinganum (1981) shows that firms adopt at different times even if they are initially identical. Fudenberg and Tirole (1985) study the duopoly case in which firms attempt to preempt innovation because the leader earns more than the follower. In that case, there is still a leader and a follower, but they earn the same actualized value. Considering both cases, Jeanjean (2017) investigates the impact of technical progress on technological adoption. The higher the technical progress is, the higher is the level of innovation given an equal cost of adoption or the lower the cost of adoption for an equal level of innovation. When the technical progress is greater, firms adopt earlier on average. However, there is a threshold to this effect because firms cannot adopt before an innovation is developed. Technical progress, which stimulates the impact of competitive pressure, tends to advance the leader's date of adoption and to delay that of the follower, with a positive overall effect on industry-level investment because the former effect is larger than the latter. However, the threshold stops this dynamic. Beyond the level of competition at which the leader adopts immediately, an increase in competitive pressure can no longer advance the adoption time of the leader but still delays that of the follower. As a result, industry-level investment decreases. Technical progress thus reduces the threshold in the level of competition at which this trend is reversed.

3 Why Does Technical Progress Tend to Reduce the Degree of Competition that Maximizes Investment?

In this section, I use the Schumpeterian growth model described in Aghion et al. (2014), mentioned in the literature review.

3.1 The Inverted U-Shaped Relationship

The Schumpeterian growth model explains why the relationship between competition and innovation is inverted U-shaped. Competition reduces both pre- and post-innovation profits. The reduction in pre-innovation profits encourages firms to innovate to restore their margins; this is the escape competition effect. In contrast, a reduction in post-innovation profit hinders firms' innovation. This is the Schumpeterian effect. In the model, the escape competition effect is represented by symmetric duopolies engaged in neck-and-neck competition, with both competitors using the same technology. The Schumpeterian effect is represented by asymmetric duopolies with a leader and a follower. The leader exerts monopoly power because it uses a higher level of technology, and the follower sells nothing but is willing to innovate to catch up with the leader. When a competitor innovates, in symmetric competition, it acquires monopoly power; consequently, the duopoly becomes asymmetric.

When the follower innovates in the asymmetric duopoly, it catches up with the leader, and the duopoly becomes symmetric. Duopolies thus alternate between symmetric and asymmetric forms. When the symmetric form prevails, the escape competition effect dominates, and the global effect is that competition fosters innovation; thus, the slope of the relationship between competition and innovation is increasing. When the asymmetric form prevails, the Schumpeterian effect dominates, and the global effect is that competition hampers innovation; thus, the slope of the relationship between competition and innovation is decreasing.

An increase in competitive intensity strengthens the attractiveness of innovation in symmetric markets and reduces it in asymmetric markets. As a result, firms in symmetric markets are more likely to innovate and to move toward the asymmetric form. Conversely, firms in the asymmetric form are less likely to innovate and to move toward the symmetric form. Consequently, an increase in competition tends to reduce the symmetric form to the benefit of the asymmetric form. This fosters the Schumpeterian effect to the detriment of the escape competition effect. A higher competitive intensity thus increases the probability that the Schumpeterian effect prevails. In other words, an increase in competitive intensity decreases the slope of the relationship between competition and innovation. This decreasing slope generates the inverted U shape: A low intensity of competition is more likely to provide an increasing slope because the escape competition effect prevails, whereas a high intensity of competition is more likely to provide a decreasing slope because the Schumpeterian effect prevails.

3.2 What Is the Impact of Technical Progress on the Relationship Between Competition and Investment?

Greater technical progress increases the size of innovation. A larger size of innovation increases both the profits of the leader in asymmetric competition and the profits of the two rivals in symmetric duopolies. However, it increases the profit of the leader in an asymmetric duopoly more. As a result, a larger level of innovation increases the innovative effort of the symmetric rivals (in their attempts to become the leader in an asymmetric duopoly) more than that of the followers in asymmetric competition (in their attempts to become a rival in a symmetric duopoly). There are thus more changes from symmetric to asymmetric duopoly than in the reverse case. This strengthens the Schumpeterian effect to the detriment of the escape competition effect, and this tends to decrease the slope of the relationship between competition and innovation regardless of the initial degree of competitive pressure.

Consider an inverted U-shaped relationship between competition and innovation. The slope of this relationship is flat for the degree of competition that maximizes innovation. A larger size of innovation, by decreasing the slope of the relationship, moves the maximum of the inverted U-shaped curve to the left and toward a lower degree of competition.

In other words, a larger level of innovation has a greater impact on post-innovation profit than pre-innovation profit. The Schumpeterian effect is more sensitive to post-innovation profit, and the escape competition effect is more sensitive to pre-innovation profit. Technical progress impacts profits by increasing the size of innovation. As a result, a larger size of innovation strengthens the Schumpeterian effect more than it does the escape competition effect and, therefore, decreases the slope of the relationship between competition and innovation. Since more innovative effort requires more investment, we can conclude that greater technical progress tends to decrease the level of competition that maximizes investment.

3.3 Illustration: American Productivity Growth in Recent Decades

The decrease in the level of competition that maximizes investment is consistent with the pattern of American productivity growth in recent decades: a drop in the long term after a burst in the short term. Aghion et al. (2019) explain this pattern as the result of the technological progress induced by the IT wave of the 1990s. According to the authors, this technical advance reduced the cost of operating different product lines. This benefited the most efficient firms, which have diversified more than others. As a result, the proportion of high-efficiency firms increased across most product lines.

In the short run, this increased efficiency had a positive impact on productivity, but in the long run, it entailed a decline. This decline is explained by the fact that to enter a new market (a new product line), the probability of facing a high-efficiency firm is higher, and therefore, the benefit of investing in innovation is lower. As a result, firms curtail their innovation effort. This is the Schumpeterian effect, where the drop in expected post-innovation profits reduces investment.

In other words, in many product lines or industries, the IT wave reinforced the Schumpeterian effect at the expense of the escape competition effect, and this shifted the top of the inverted U relationship toward a lower degree of competition. Indeed, the peak of the curve separates the increasing part, where the escape competition effect prevails, and the decreasing part, where the Schumpeterian effect prevails. This shift, at the beginning, brings the industries lying in the increasing part of the curve closer to the peak and leads to an increase in investment; this is the burst. Then, if the movement continues, industries end up in the decreasing part of the curve, where investment decreases. If the movement is large enough, the final investment may be lower than the initial investment. If such a phenomenon occurs in many industries, it can lead to a long-term decline after a short-term burst, as described by Aghion et al. (2019).

4 The Model

The previous section highlights the mechanism that allows technical progress to decrease the level of competition that maximizes investment. This section illustrates these results in an oligopoly context where competition is modeled both as the degree of horizontal differentiation (or more precisely substitutability) and the number of competitors. This model will be used first in a symmetric market where the parameter of competition we are interested in is the number of firms and, second, in an asymmetric market where the parameter of competition we are interested in is the degree of horizontal substitutability. In the symmetric case, there is a trade-off between the number of firms and the incentives to invest for each firm. An increase in the number of firms tends to decrease the incentives to invest for each firm but increases the number of firms that invest. Each firm's incentives to invest represent the Schumpeterian effect. An increase in the number of firms increases the competitive pressure and tends to decrease the amount of investment per firm. The number of firms that invest represents the escape competition effect. An increase in the number of firms decreases the amount of investment per firm but increases the number of firms that invest.

Technical progress tends to amplify the fall in each firm's investment caused by the presence of additional firms. This strengthens the Schumpeterian effect and thus shifts the trade-off toward a smaller number of firms.

In the asymmetric case, competition increases the investment of the most efficient firms, which is the escape competition effect, but reduces the investment of the least efficient firms, which is the Schumpeterian effect. For a low initial level of competition, competition increases industry-level investment. However, the least efficient firm cannot remain in the market above a certain level of competition. Industry-level investment is maximized for this threshold level of competition.The mechanism in the asymmetric case is similar to that of the innovation race described by Reinganum (1981) and Jeanjean (2017) presented in the literature review. In this case too, technical progress strengthens the Schumpeterian effect more than the escape competition effect, and decreases the threshold level of competition at which the least efficient firm cannot remain in the market.

4.1 Settings of the Model

To demonstrate these effects, I choose a model of oligopoly with differentiated goods, similar to that of Motta and Tarantino (2017) or Bourreau et al. (2018), in which n firms compete on price. The demand for the good produced by firm i is given by $q_i(p_i, p_{-i})$, where p_i is the price of firm i and p_{-i} is the vector of prices of the $n - 1$ firms other than firm i.

Firms simultaneously set their price and their cost-reducing investment. Firm i chooses its cost-reducing investment x_i such that its marginal cost decreases from c_{0i} to c_i, such that $c_i(x_i) = c_{0i} - x_i$. Firm i sets its price p_i and cost-reducing investment x_i to maximize its profit π_i. The cost of investment is $F(x_i) = x_i^2/2\tau$, where τ represents the degree of technical progress or, more precisely, the ease of innovation. The higher τ is, the lower the cost of innovation for a given cost reduction x_i, so the innovation is easier.

This model implicitly assumes that product innovation does not change the parameters of consumer demand or the definition of the market. Technical progress lowers production costs for equal quality, but it does not dramatically change the mode of consumption or consumer preferences.

The profit of firm i is as follows:

$$\pi_i(p_i, p_{-i}, x_i) = (p_i - c_i(x_i))q_i(p_i, p_{-i}) - F(x_i) \tag{1}$$

The solution of the maximization problem leads to two first-order conditions, one for the price and the other for the investment:

$$\frac{\partial \pi_i}{\partial p_i} = q_i(p_i, p_{-i}) + \frac{\partial q_i(p_i, p_{-i})}{\partial p_i}(p_i - c_i(x_i)) = 0 \tag{2}$$

$$\frac{\partial \pi_i}{\partial x_i} = -c_i'(x_i)q_i(p_i, p_{-i}) - F'(x_i) = 0 \tag{3}$$

Equation (3) provides $x_i = \tau q_i$.

A firm with no output is excluded from the market. This means that the number of firms tends to decrease for a higher degree of horizontal substitutability.

An increase in technical progress entails an increase in investment x_i, which decreases the marginal cost c_i. The demand function is given by Shubik and Levitan (1980):

$$U(q_1,\ldots q_n)=\sum_{i=1}^{n}\alpha_i q_i-\frac{1}{2}\left(\sum_{i=1}^{n} q_i^{\,2}+\gamma\sum_{i\neq j} q_i q_j\right)-\sum_{i=1}^{n} p_i q_i \tag{4}$$

where $a_i > 0$, and $\gamma \in [0, 1]$ represents horizontal product substitutability. $\gamma = 0$ means that products are independent and firms act as monopolists, and $\gamma = 1$ means that products are perfect substitutes.

I assume that $\tau \in]0, 2[$ and $c_{0i} < a_i$ to ensure that x_i and q_i are positive.

$\tau = 0$ corresponds to the case where there is no technical progress. In this case, a decrease in marginal cost x_i, as small as it is, would lead to an infinite cost of investment. The case $\tau \geq 2$, with the demand function in equation (4), would lead to negative or infinite values of q in some cases, which is not realistic. $\tau \in]0, 2[$ avoids such unrealistic cases. In the same manner, if $c_{0i} \geq a_i$ then $q \leq 0$, as shown in Eq. (5) below. $c_{0i} < a_i$ avoids these unrealistic cases.

4.2 Symmetric Market

To evaluate the impact of technical progress on the relationship between competition and investment when competition is measured as the number of firms, it is better to consider a symmetric market. In that case, all firms have the same price, the same output, and the same investment. To simplify the notation, the firm index is removed. Equation (2) leads to output per firm:

$$q=\frac{(1+\gamma(n-2))(a-c_0)}{(1-\gamma)(1+\gamma(n-1))-(1+\gamma(n-2))\tau+(1+\gamma(n-1))(1+\gamma(n-2))} \tag{5}$$

and its derivative with respect to n is as follows:

$$q'=\frac{\left((1-\gamma)\gamma-(1+\gamma(n-2))^2\right)\gamma(a-c_0)}{((1-\gamma)(1+\gamma(n-1))-(1+\gamma(n-2))\tau+(1+\gamma(n-1))(1+\gamma(n-2)))^2} \tag{6}$$

The cost of investment per firm is then $F = x^2/2\tau$. The cost $= \tau q^2/2$. At the industry level, the cost of investment is $F_{ind} = nF = n\tau q^2/2$.

The number of firms has a negative relationship with output and investment per firm. What is the impact of the number of firms on industry-level investment?

The derivative of industry-level investment with respect to n is $F'_{ind} = \tau q\left(\frac{q}{2}+nq'\right)$ and the first-order condition $F_{ind}(n^*) = 0$ leads to $n^* = -\frac{q}{2q'}$.

The number of firms n is an integer; however, in the following, the integer problem is ignored, but that does not make the model unrealistic.

Lemma 1. *The relationship between the number of firms and industry-level investment is decreasing or inverted U-shaped.*

Proof: I first show that if investment in the industry reaches an optimum, this is a maximum and this maximum is absolute, as there is no relative minimum. In that case, the relationship is inverted U-shaped.

Then, I show that if there is no optimum, the relationship cannot be monotonically increasing because investment in the industry tends toward zero when the number of firms tends toward infinity. The relationship is thus monotonically decreasing (see details in the appendix).

Proposition 1. *An increase in technical progress decreases the number of firms that maximizes industry-level investment.*

Proof: When the relationship is inverted U-shaped, I first calculate the expression of the number of firms that maximizes investment in the industry, $n^* = -q/2q'$, and then I derive it with respect to technical progress, τ; I find that the expression is negative which means that the number of firms that maximizes investment in the industry tends to decrease with technical progress.

When the relationship is monotonically decreasing, investment in the industry is higher in monopoly than in symmetrical duopoly. I compare the expressions, and then I derive them with respect to technical progress; I find that technical progress, τ, widens the gap and keeps the relationship monotonically decreasing (see details in the appendix).

The graph below (Fig. 1) shows the number of firms required to maximize industry-level investment, n^*, as a function of technical progress, τ. The different colors correspond to different degrees of horizontal substitutability, γ. n^* is an integer, which explains the staircase-shaped lines.

Clearly, technical progress decreases the number of firms that maximizes industry-level investment. The decreasing slope tends to become less steep as the degree of horizontal substitutability increases. This suggests that technical progress acts as a dynamic form of competition. An increase in horizontal substitutability, which is a static form of competition, tends to reduce the degree of technical progress required to achieve the same number of firms n^*. Similarly, an increase in horizontal substitutability decreases the number of firms n^* for a given degree of technical progress.

4.2.1 Price Evolution

Competition is generally considered to lower prices. This is the case when dynamic effects are negligible compared with static effects. However, the opposite can occur when dynamic effects are sufficiently high. Indeed, if τ is high enough, investment in cost reduction can reduce marginal cost more than the increase in the profit margin. In this case, competition may raise prices.

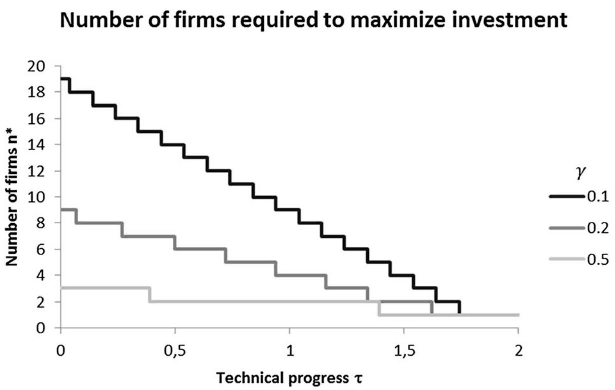

Fig. 1 Technical progress and the number of firms that maximize investment

Proposition 2. *If technical progress* $\tau \geq 1/(1-\gamma)$*, the number of firms always increases price. If technical progress is such that* $1-\gamma < \tau < 1/(1-\gamma)$*, the relationship between price and the number of firms is U-shaped, and if* $\tau \leq 1-\gamma$*, the number of firms always decreases price (see proof in the appendix).*

The intuition is that if technical progress amplifies the impact of the number of firms on output, the higher the technical progress, the higher is the decrease in output following an increase in the number of firms, and therefore, the higher the increase in price.

4.2.2 Consumer Surplus and Welfare

Industry-level investment also impacts consumer surplus and welfare. Technical progress tends to increase industry-level investment, which in turn increases the quality or efficiency of firms. This tends to also increase consumer surplus and welfare. However, this section shows that technical progress also reduces the number of firms that maximizes consumer surplus and welfare.

$$CS = \frac{F_{ind}(1+\gamma(n-1))}{\tau} \tag{7}$$

$$W = n\pi + CS = (a-c_0)nq + F_{ind} - CS \tag{8}$$

Lemma 2. *For* $\gamma > 0$*, if* $\tau \leq 3(1-\gamma)/2$*, the relationship between the number of firms and consumer surplus is increasing.*

If $\tau > 3(1-\gamma)/2$*, the relationship between the number of firms and consumer surplus is decreasing or inverted U-shaped.*

If $\tau \leq 1-\gamma$*, the relationship between the number of firms and welfare is increasing.*

If $\tau > 1-\gamma$*,the relationship between the number of firms and welfare is decreasing or inverted U-shaped. (See proof in the appendix).*

The intuition of Lemma 2 derives from the fact that for a weak technical progress, generating a low pace of innovation (low τ), dynamic efficiency is not strong enough to compensate for static efficiency. As consumer surplus is mainly driven by static efficiency, it increases with the number of firms. If technical progress is high enough, the dynamic efficiency outweighs the static efficiency above a certain number of firms. The same occurs with total welfare; however, the level of technical progress required to outweigh the static effect is lower because profit decreases with the number of firms.

Proposition 3. *The number of firms that maximizes consumer surplus is equal to or higher than the number that maximizes investment in the industry, and the number of firms that maximizes total welfare is equal to or lower than the number that maximizes consumer surplus.*

Investment at the industry level is driven by the dynamic efficiency whereas consumer surplus is driven not only by dynamic efficiency derived from investment but also by static efficiency. When the number of firms is lower than the number that maximizes investment in the industry, an increase in the number of firms increases both static and dynamic efficiency and thus increases consumer surplus. However, when the number of firms is higher than the number that maximizes investment in the industry, an increase in the number of firms still increases static efficiency but decreases dynamic efficiency, which is the reason why the number of firms that maximizes consumer surplus is higher or equal to the number that maximizes the investment in the industry.

Welfare is the sum of consumer surplus and profit. Intuitively, an increase in the number of firms improves consumer surplus more than welfare; therefore, the number of firms that maximizes welfare is lower or equal to the number that maximizes consumer surplus. The number of firms that maximizes welfare may be higher, equal to, or lower than the number that maximizes investment in the industry.

Proposition 4. *An increase in technical progress decreases the number of firms that maximizes consumer surplus and welfare (see the proof in the appendix).*

The intuition of proposition 4 derives from proposition 1. Dynamic efficiency is maximized for a certain number of firms that decreases with technical progress, τ. Static efficiency does not depend on technical progress; as a result, the number of firms that maximizes consumer surplus and welfare decreases with technical progress τ, in line with the number of firms that maximizes investment in the industry.

4.3 Asymmetric Market

In this part, I allow firms to have different efficiency level or different qualities. $\exists i, j; i \neq j$ such that $c_{0i} \neq c_{0j}$ or $a_i \neq a_j$. In this section, I regard competition as a friction among firms represented by the degree of substitutability.

This difference in efficiency or in quality entails an asymmetry in the market. Substitutability increases competitive pressure in the market, and as noted by Boone (2008), competitive pressure reallocates output from less-efficient to more-efficient firms. The market share of the least efficient firm tends to decrease with substitutability until it falls to zero. There is a degree of limit substitutability, γ^*, above which the least efficient firm cannot remain on the market. Technical progress, which fosters investment, tends to increase asymmetry and thereby reduces the degree of limit substitutability. The amount of investment per firm, $F(q_i)$, is a convex function of output q; in the model, $F(q_i) = \tau q_i^2/2$. The reallocation of output from the least efficient firm to more efficient firms thus leads to an increase in industry-level investment (see the proof in the appendix). This is the maverick effect.

Lemma 3. *For a given level of technical progress, τ, if F_{ind} (0) > F_{ind} (γ^*), then the inequality remains true for any higher level of technical progress (see the proof in the appendix).*

This means that if the investment in the industry is maximized when products are completely differentiated, $\gamma = 0$, then an increase in technical progress, τ, preserves this pattern.

Proposition 5. *An increase in technical progress decreases the degree of substitutability that maximizes industry-level investment.*

For a low initial degree of substitutability, an increase in substitutability tends to decrease output and thus industry-level investment, because consumers make fewer multiple purchases. Then, in the vicinity of the substitutability threshold, the maverick effect tends to increase industry-level investment. As a result, industry-level investment, as a function of substitutability, γ, has a U-shaped relationship with $\gamma = 0$ and the substitutability threshold $\gamma = \gamma^*$. This means that the degree of substitutability that maximizes industry-level investment is 0 or γ^*. By Lemma 3, if F_{ind} (0) > f_{ind} (γ^*) for a given level of technical progress, τ, then the inequality remains true for a higher level of technical progress. We have seen that an increase in technical progress decreases the limit γ^*; therefore, an increase in technical progress tends to decrease the degree of substitutability that maximizes industry-level investment.

The graph below (Fig. 2) represents the degree of substitutability that maximizes investment as a function of technical progress. The dotted curve represents γ^*, and the solid black curve represents the maximizing level of substitutability. Those two curves are merged for $\tau < \tau^*$ before it falls to zero.

The solid gray curve represents the maximizing substitutabilities for an alternative demand function from Singh and Vives (1984):

$$p_i = a_i - \frac{1}{1+\gamma}\left(q_i + \gamma \sum_{j \neq i} q_j\right)$$

This curve does not fall to zero above a certain level of technical progress. In both cases, the degree of substitutability decreases with technical progress.

The parameters chosen for this figure are as follows: $n = 2$, $(a_i - c_{0i}) = 0.45$, and $(a_j - c_{0j}) = 0.35$. For those parameters, $\tau^* \sim 1.441$.

4.3.1 Consumer Surplus and Welfare

Equation (4) allows for the calculation of consumer surplus

$$CS(\gamma) = \frac{1}{2}\left(\sum_{i=1}^{n} {q_i}^2 + \gamma \sum_{j \neq i} q_i q_j\right) \tag{9}$$

and welfare:

$$CS(\gamma) = \frac{1}{2}\left(\sum_{i=1}^{n} {q_i}^2 + \gamma \sum_{j \neq i} q_i q_j\right) \tag{10}$$

The degree of substitutability that maximizes industry-level investment also maximizes welfare.

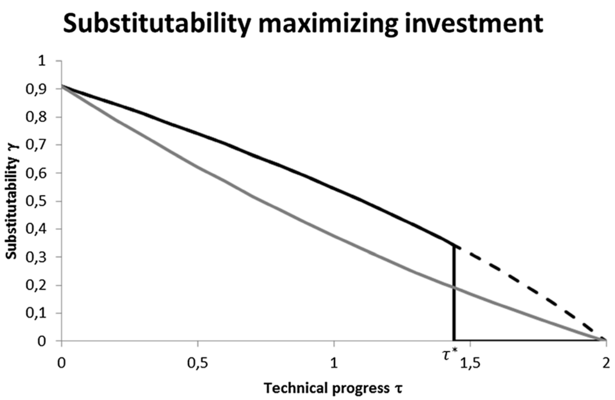

Fig. 2 technical progress and the level of substitutability that maximizes industry-level investment

For $n = 2$, the degree of substitutability that maximizes industry-level investment also maximizes consumer surplus.

For $n > 2$, the degree of substitutability that maximizes consumer surplus is $\gamma = \gamma^*$ if technical progress is relatively low and $\gamma = 0$ otherwise.

As a result, an increase in technical progress decreases the degree of substitutability that maximizes consumer surplus and welfare.

4.4 Merger Considerations and the Maverick Effect

Although this model does not specifically study mergers, it can be useful to compare industry-level investment according to the number of firms in asymmetric markets. What happens if the least efficient firm exits?[2]

In a symmetric market, a decrease in the number of firms increases industry-level investment provided that technical progress, τ, and substitutability are high enough (see Fig. 1). For a given level of technical progress, there is a degree of substitutability above which a merger generates investment.In an asymmetric market, the maverick effect may reverse the trend in the vicinity of the substitutability threshold, γ^*. The graph below (Fig. 3) represents industry-level investment with respect to substitutability for 2, 3, and 4 firms.

In this figure, the parameters are as follows: $(a_1 - c_{01}) = 0.34$; $(a_2 - c_{02}) = 0.32$; $(a_2 - c_{02}) = 0.28$; $(a_2 - c_{02}) = 0.26$ and $\tau = 0.8$.

Note that for low substitutabilities, as for symmetric markets (see Fig. 4 in the appendix), investment is higher with more firms, and mergers reduce investment (up to approximately $\gamma = 0.2$ in the example in Fig. 3). For intermediate substitutabilities, investment is higher with fewer firms, and mergers are favorable for investment. However, in the vicinity of γ^*, the maverick effect straightens the investment curve, and investment again increases in the number of firms.

Asymmetry in the market, tends to increase industry-level investment through the maverick effect. This reduces the opportunities for mergers compared with the symmetric case (compare with Fig. 4 in the appendix.) An increase in technical progress reduces the values of γ^* above which the least efficient firm has to exit, and therefore, an increase in technical progress reduces the number of viable firms in the market.

5 Conclusion

This paper shows that technical progress tends to reduce the degree of competition (measured as the number of firms or as the degree of substitutability) that maximizes investment at the industry level provided that innovation does not dramatically change the mode of consumption or consumer preferences. This feature also holds for the relationship between competition and consumer surplus and between competition and welfare.

Technical progress, which is understood as technological opportunity and is specific to each industry, reduces the cost of investment, and represents an effort to improve efficiency. The greater the technological progress is, the more firms are encouraged to improve efficiency, and the more they invest. This race for investment is, in a sense, a form of dynamic competition. As

[2] The least efficient firm may merge with a more efficient one. The merged firms decide not to maintain both offerings. This is particularly likely to happen if substitutability is high enough (Haucap et al. 2019)

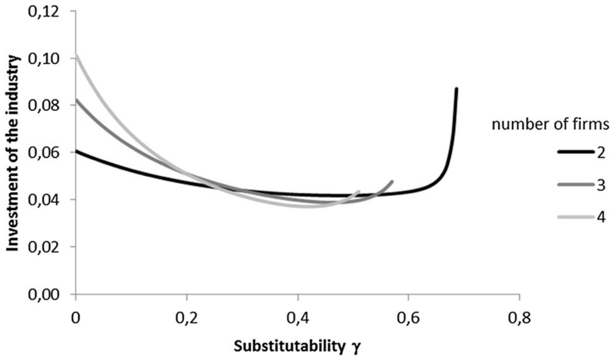

Fig. 3 Industry-level investment with respect to the number of firms

a result, when there is a level of competition that maximizes investment in an industry, a higher level of technical progress in another industry, all other things being equal, strengthens dynamic competition and requires a lower degree of the other form of competition, namely, static competition (the number of competitors or substitutability), to reach the optimal level.

Competition tends to reduce non-investment profits and to increase the profit differential before and after investment. This leads to two contradictory effects: the escape competition effect, whereby competition increases investment; and the Schumpeterian effect, whereby competition decreases investment. Greater technical progress strengthens the Schumpeterian effect more than it does the escape competition effect and thus decreases the level of competition that maximizes investment.

In the case of competition measured by the number of competitors, in symmetric markets, or in the case of competition measured by the degree of horizontal substitutability, in asymmetric markets, the catalytic effect of technical progress on competition entails a reduction in the degree of competition that maximizes industry-level investment. As investment impacts consumer surplus and welfare, technical progress also tends to reduce the level of competition that maximizes consumer surplus and welfare.

This property of technical progress has policy implications. In industries in which the level of technical progress is high, the degree of competition should be adjusted to a lower level than that in industries with a lower level of technical progress in order to maximize investment, consumer surplus, and welfare.

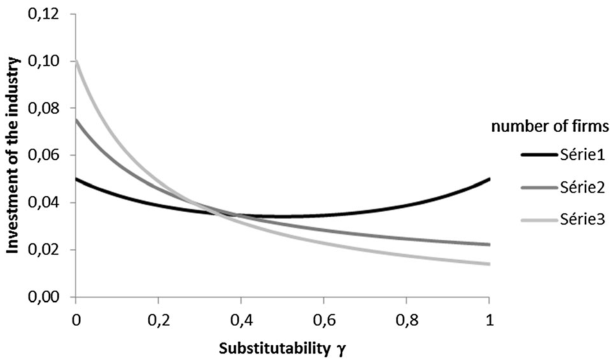

Fig. 4 Industry-level investment with respect to the number of firms in a symmetric market

This requires, in practice, an accurate assessment of the level of competition that maximizes investment in the industry. This assessment is all the easier to do when the market is stable, in the sense that innovation improves the quality of products (increases consumer utility and willingness to pay) or decreases the cost of production for equal quality, without dramatically changing the mode of consumption or consumer preferences. For example, in the telecom industry, traffic increases exponentially over time. Customers consume increasingly more at a relatively stable price. While innovation considerably reduces the production cost of the megabyte, it does not significantly modify the determinants of competition or behavior of consumers, whose spending remains relatively stable, despite ever increasing quantities.

In emerging markets, when innovation completely modifies the nature of consumption, determinants of competition and investment may change very quickly and make the assessment more difficult. For example, the arrival of MP3 completely shook up the music industry, whose revenues were halved between 1999 and 2009. The mode of consuming music has radically changed turning from a material format to an intangible format.

This paper highlights a theoretical proposition; a comparison of different industries displaying different levels of technological progress would be useful to empirically test this theory.

Appendix

Proof of Lemma 1

The relationship between the number of firms and industry-level investment is decreasing or inverted U-shaped.

Investment at industry level is $F_{ind} = \frac{n\tau q^2}{2}$.

Let us denote $F'_{ind} = \frac{\partial F_{ind}}{\partial n}, q\} = \frac{\partial q'}{\partial n}$, and $F\}_{ind} = \frac{\partial F'_{ind}}{\partial n}$.

We can write $F'_{ind} = \tau q\left(\frac{q}{2} + nq'\right)$ *and* $F\}_{ind} = \tau q'\left(\frac{q}{2} + nq'\right) + \tau q\left(\frac{3q'}{2} + nq\}\right)$.

First-order condition ($F_{ind} = 0$) provides the number of firms for which investment of the industry reaches an optimum. This optimum is a maximum if the second order condition ($F"_{ind} < 0$) is verified.

I will first show that if there is an optimum, then it is a maximum and it is unique. That is to say if $F_{ind} = 0$ and $F"_{ind} < 0$.

From Eq. (6),

$$q\} = \frac{2\gamma^2\Big((1+\gamma(n-2))^3 + (1-\gamma)\gamma(\tau-1-3(1+\gamma(n-2)))\Big)\gamma(a-c_0)}{((1-\gamma)(1+\gamma(n-1))-(1+\gamma(n-2))\tau + (1+\gamma(n-1))(1+\gamma(n-2)))^3} \qquad (11)$$

Functions F_{ind}, F'_{ind}, and $F"_{ind}$ are continuous for $n \in \mathbb{R}$ and $n \geq 1$ because the denominator of Eqs. (5), (6), and (11) are different from zero since $\tau < 2$.

If there is an optimum, then $F' = 0$; therefore, $\frac{q}{2} + nq' = 0$ or $\tau q = 0$. Yet by definition, $\tau > 0$ and $q > 0$ since $a > c_0$. As a result, if there is an optimum for $n = n^*$, then $n^* = -\frac{q}{2q'}$.

At the optimum, the sign of $F"_{ind}$ is the sign of $\frac{3q'}{2} + nq\}$ because τq is strictly positive.

We can write $\frac{3q'}{2} + n^* q\} = \frac{3q' - qq\}}{2q'}$ using $n^* = -\frac{q}{2q'}$.

From Eq. (6), we can check that for $n \geq 2$, q' < 0; thus, the sign of $F"_{ind}$ is the sign of $qq" - 3q'$.

Using Eqs. (5), (6), and (11), we can write the following:

$$qq''-3q' = -\frac{\left(3(1-\gamma)^2\gamma^4 + \gamma^2(1+\gamma(n-2))^4 + 2\gamma^3(1-\gamma)(1+\gamma(n-2))(1-\tau)\right)(a-c_0)^2}{((1-\gamma)(1+\gamma(n-1))-(1+\gamma(n-2))\tau + (1+\gamma(n-1))(1+\gamma(n-2)))^4}$$

The denominator of this expression, as those of Eqs. (5), (6), and (11), is strictly positive since $\tau \in]0, 2[$.

If $n \geq 2$, then $1+\gamma(n-2) \geq 1$, and thus, $2\gamma^3(1-\gamma)(1+\gamma(n-2))(1-\tau) \geq 2\gamma^3(1-\gamma)(1-\tau)$.

Furthermore, $(1-\tau) > -1$, and as a result, $2\gamma^3(1-\gamma)(1-\tau) > -\frac{\gamma^2}{2}$, the numerator is positive.

This means that $qq'' - 3q'$ is negative and thus $F''_{ind} \leq 0$. The optimum is a maximum.

In summary, if $\exists n^* \geq 2$ such that $F'(n^*) = 0$ then $F''_{ind}(n^*) \leq 0$ then n^* is a maximum.

This maximum is unique because there is no minimum. Indeed, it is not possible to have a second relative maximum without a relative minimum as functions F_{ind} *and* F'_{ind} are continuous.

If there is no optimum, the relationship cannot be monotonically increasing because $F_{ind}(n) = \tau q^2/2$, and from equation (5)

$$\lim_{n \to +\infty} F_{ind}(n) = 0$$

If investment of the industry is maximized for $n = 1$, then function $F_{ind}(n)$ is monotonically decreasing because there is no relative minimum.

As a result, the relationship between the number of firms and industry-level investment is inverted U-shaped or monotonically decreasing.

Proof of Proposition 1: From Lemma 1, the relationship between the number of firms and industry-level investment is inverted U-shaped or monotonically decreasing.If the relationship is inverted U-shaped, the number of firms n^* that maximizes industry-level investment is such that $F'(n^*) = 0$, which means $n^* = -q/2q'$.

How does n^* move when technical progress, τ, increases?

Output q tends to increase with technical progress, deriving q from Eq. (5) with respect to τ yields:

$$\frac{\partial q}{\partial \tau} = \frac{q^2}{(a-c_0)}$$

Moreover, deriving q' from Eq. (6) yields:

$$\frac{\partial q'}{\partial \tau} = \frac{2qq'}{(a-c_0)}$$

As a result,

$$\frac{\partial n^*}{\partial \tau} = \frac{q^2}{2q'(a-c_0)}$$

If $n^* \geq 2$ then $q' < 0$; therefore, $\frac{\partial n^*}{\partial \tau} \leq 0$. This means that if the relationship between competition and investment of the industry is inverted U-shaped, the number of firms that maximizes investment of the industry decreases with technical progress.

If the relationship is monotonically decreasing, this means that $n^* = 1$.

Investment of the industry is $F_{ind}(1) = \frac{\tau(a-c_0)^2}{2(2-\tau)^2}$; furthermore, $F_{ind}(2) = \frac{\tau(a-c_0)^2}{(2-\tau+\gamma(1-\gamma))^2}$;

F_{ind} decreasing means $F_{ind}(1) > F_{ind}(2)$, and $\tau > 2-\frac{\gamma(1-\gamma)}{\sqrt{2}-1}$. What happens if τ increases?

$\frac{\partial F_{ind}(1)}{\partial \tau} = \frac{\left(4-\tau^2\right)(a-c_0)^2}{2(2-\tau)^4}$ and $\frac{\partial F_{ind}(2)}{\partial \tau} = \frac{\left(4-\tau^2+\gamma(1-\gamma)(4+\gamma(1-\gamma))\right)(a-c_0)^2}{(2-\tau+\gamma(1-\gamma))^4}$

We can check that if $\tau > 2-\frac{\gamma(1-\gamma)}{\sqrt{2}-1}$, then $\frac{\partial F_{ind}(1)}{\partial \tau} > \frac{\partial F_{ind}(2)}{\partial \tau}$.

This means that if the relationship is monotonically decreasing, an increase in technical progress widens the gap and keeps the decreasing shape of the curve. In any case, an increase in technical progress tends to decrease (never increase) the number of firms that maximizes investment of the industry.

Proof of Lemma 2

Let us denote $CS' = \frac{\partial CS}{\partial n}$ and $W' = \frac{\partial W}{\partial n}$

From Eq. (7), it can be written as follows:

$$CS' = \frac{F'_{ind}(1+\gamma(n-1)) + \gamma F_{ind}}{\tau}$$

And from Eq. (8):

$$W' = (a-c_0)(q+nq') + F'_{ind} - CS'$$

If $\tau \le \frac{3(1-\gamma)}{2}$, then $CS' > 0$ which means that CS is monotonically increasing.

If $\tau > \frac{3(1-\gamma)}{2}$, then CS' may be positive for low values of n, but CS' is negative for high values of n which means that CS is inverted U-shaped or monotonically decreasing.

If $\tau \le (1-\gamma)$, then $W' > 0$ which means that W is monotonically increasing.

If $\tau > (1-\gamma)$, then W' may be positive for low values of n, but W' is negative for high values of n which means that W is inverted U-shaped or monotonically decreasing.

Proof of proposition 2:

From Eq. (4), it can be written as follows:

$$p_i = a_i - q_i - \gamma \sum_{i \ne j} q_j$$

In symmetric market, this equation becomes $p = a - (1 + \gamma(n - 1))q$. The derivative of the price according to n can be written $p' = -(\gamma q + (1 + \gamma(n - 1))q')$ which yields using Eqs. (5) and (6):

$$p' = \frac{\gamma\left((1+\gamma(n-2))^2\tau - (1-\gamma)(1+\gamma(n-1))^2\right)(a-c_0)}{((1-\gamma)(1+\gamma(n-1)) - (1+\gamma(n-2))\tau + (1+\gamma(n-1))(1+\gamma(n-2)))^2} \tag{12}$$

The denominator is positive, thus the sign of p' is the sign of the numerator. $p' \ge 0$ if $\tau \ge (1-\gamma)\left(\frac{1+\gamma(n-1)}{1+\gamma(n-2)}\right)^2$. Price is increasing if τ is high enough. $(1-\gamma)\left(\frac{1+\gamma(n-1)}{1+\gamma(n-2)}\right)^2$ is decreasing with n, as a result, the probability that $p' > 0$ increases with n.

For $n = 1$, price is increasing if $\tau \geq \frac{1}{1-\gamma}$ and

$$\lim_{n \to +\infty} (1-\gamma)\left(\frac{1+\gamma(n-1)}{1+\gamma(n-2)}\right)^2 = 1-\gamma$$

As a result, if $\tau \geq \frac{1}{1-\gamma}$, then $p' \geq 0$ for all values of n; this means that the number of firms always increases price.

If $\tau \leq 1-\gamma$, then $p' \leq 0$ for all values of n; this means that the number of firms always decreases price.

If $(1-\gamma) < \tau < \frac{1}{1-\gamma}$, then price is decreasing for low values of n and increasing for high values. The relationship between price and the number of firms is U-shaped.

Proof of Proposition 4:

From Lemma 2, consumer surplus and welfare are monotonically increasing if τ is under a certain level. An increase in technical progress may cross the threshold and thus decrease the number of firms maximizing consumer surplus or welfare.

The number of firms that maximizes consumer surplus or welfare is denoted n^{**} and n^{***}, respectively. If consumer surplus or welfare is monotonically decreasing, then the number of firms that maximizes consumer surplus or welfare is $n^{**} = 1$ and $n^{***} = 1$, respectively. In such cases, $CS'(1) < 0$ or $W'(1) < 0$

and $\frac{\partial CS'(1)}{\partial \tau} < 0$ or $\frac{\partial W'(1)}{\partial \tau} < 0$.

If the relationship between the number of firms and consumer surplus or welfare is inverted U-shaped, the number of firms that maximizes consumer surplus is such that $CS'(n^{**}) = 0$ or $W'(n^{***}) = 0$. In that case, $\frac{\partial CS'(n^{**})}{\partial \tau} < 0$ or $\frac{\partial W'(n^{***})}{\partial \tau} < 0$. This means that the number of firms that maximizes consumer surplus or welfare decreases with technical progress.

Reallocation of Output Tends to Increase Industry-Level Investment

Investment of firm i is $F_i = \tau q_i/2$. Investment of the industry is

$$F_{ind} = \frac{\tau}{2} \sum_{i=1}^{n} q_i^2$$

Let firm i be the least efficient firm: $\forall j \neq i$, $q_i < q_j$. The reallocation of output decreases the output of firm i which becomes $q_i - \varepsilon_i$ and increases the output of the other firms that are more efficient: $q_j - \varepsilon_j$. The reallocation induces $\varepsilon_i = \sum_{j \neq i} \varepsilon_j$.

Investment of the industry after reallocation is written as follows:

$$F_{indar} = \frac{\tau}{2}\left((q_i + \varepsilon_i)^2 + \sum_{j \neq i}\left(q_j - \varepsilon_j\right)^2\right)$$

If $q_i < q_j$, then $\sum_{j \neq i} \varepsilon_j q_i < \sum_{j \neq i} \varepsilon_j q_j$, and thus, $\varepsilon_i q_i < \sum_{j \neq i} \varepsilon_j q_j$ which leads to $\sum_{j \neq i} \varepsilon_j q_j - \varepsilon_i q_i > 0$. As a result,

$$F_{indar}-F_{ind} = \frac{\tau}{2}\left(2\left(\sum_{j\neq i}\varepsilon_j q_j - \varepsilon_i q_i\right) + {\varepsilon_i}^2 + \sum_{j\neq i}{\varepsilon_j}^2\right) > 0$$

Proof of Lemma 3

The general expression of output of firm i can be written as follows:

$$q_i(\gamma) = \frac{B\left(\left(B^2+(1-\gamma)A-B\tau\right)(a_i-c_{0i})-\gamma B\sum_{j\neq i}\left(a_j-c_{0j}\right)\right)}{(1-\gamma)AB^2+((1-\gamma)A-B\tau)((1-\gamma)A+B(1+B-\tau))} \tag{13}$$

With $A = 1 + \gamma(n-1)$ and $B = 1 + \gamma(n-2)$.

$\gamma^*$is the value above which the least efficient firm has no output. Let j be the least efficient firm, by definition, $q_j(\gamma^*) = 0$.

For $\gamma = 0$, $\forall i,\ \ q_i(0) = \frac{(a_i-c_{0i})}{(2-\tau)}$ and

$$F_{ind}(0) = \frac{\tau\sum_{i=1}^{n}(a_i-c_{0i})^2}{2(2-\tau)^2}$$

$$F_{ind}\left(\gamma^*\right) = \frac{\tau}{2}\sum_{i\neq j}{q_{i(\gamma^*)}}^2$$

From Eq. (13), we can check that $\frac{\partial F_{ind}(0)}{\partial\tau} > \frac{F_{ind}(\gamma)}{\partial\tau}$, provided $\gamma \leq \gamma^*$. As a result, if for a given τ, $F_{ind}(0) > F_{ind}(\gamma^*)$, then, for a higher τ, $F_{ind}(0) > F_{ind}(\gamma^*)$ still holds.

For example, for $n = 2$,then $q_i(\gamma) = \frac{(2-\gamma^2-\tau)(a_i-c_{0i})-\gamma(a_j-c_{0j})}{(2-\gamma^2-\tau)^2-\gamma^2}$. If j is the least efficient firm:

$$\gamma^* = \frac{\sqrt{(a_i-c_{oi})^2+4(2-\tau)\left(a_j-c_{0j}\right)^2}-(a_i-c_{0i})}{2\left(a_j-c_{0j}\right)} \tag{14}$$

Let τ^* be the value of technical progress for which $F_{ind}(0) = F_{ind}(\gamma^*)$.

$$\tau^* = \frac{2\left(a_j-c_{0j}\right)-\left(\sqrt{(a_i-c_{oi})^2+\left(a_j-c_{0j}\right)^2}\right)\gamma^*}{\left(a_j-c_{0j}\right)} \tag{15}$$

If $\tau \leq \tau^*$, then $F_{ind}(0) \leq F_{ind}(\gamma^*)$, and if $\tau > \tau^*$, then $F_{ind}(0) > F_{ind}(\gamma^*)$.

Investment in a Symmetric Market

For this figure, the parameters are the following: $(a_i - c_{0i}) = 0.3$ and $\tau = 0.8$

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