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Technological gap and heterogeneous oligopoly

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ABSTRACT

This paper explores the effect of technological gap on output, profits, market concentration, and social welfare in quantity setting oligopoly with firms of unequal sizes, holding different conjectures, operating with non-identical costs, and producing homogenous products. Assuming firms with relatively advanced technology adopt sophisticated Cournot strategy while the remaining with backward technology behave as price takers, we find that an increase in technological gap between two types of firms may paradoxically lead to higher profits for not only the advanced but also the backward. Moreover, wider technological distance could lead to lower market concentration and be welfare enhancing.

1. Introduction

Casual empiricism suggests that firms within industries often deliberately adopt different technologies even when firms have identical opportunity sets. In the brewery industry we see breweries with large capital-intensive plants producing for both home and broad together with labor-intensive mini-breweries selling only domestically and for small segments of the local market. Steel is manufactured in large integrated steel mills as well as mini-mills that convert scrap. Paper and paper products are manufactured by companies which, variously, make or buy their supplies of wood pulp. According to empirical observation, new technologies are adopted by firms with delay and they are diffused over time. One prominent example is the computer numerically controlled machine tools (CNC) which enhances significantly productivity compared with conventional general-purpose machines. CNC became commercially available since the mid-1970s, however, as indicated by studies of the U.S. machining-intensive industries, in 1987 less than 50% of firms used CNC tools and the percentage exceeded 80% in 2002.[1]

Notwithstanding the ample example, few studies in the literature investigate the reason why firms voluntarily opt for inferior technology and hence delaying the catching-up. In this paper, we provide a model to demonstrate that wider technology gap could not only be profit-enhancing but also desirable when market competition and social welfare are concerned.

In the literature on the choice of technology, the adoption of convex technologies of different efficiencies has been explored by Eaton and Eswaran (1997), Hansen and Nielsen (2010) and, more recently, by Milliou and Petrakis (2011) and Pérez and Ponce (2015). The goal of these articles is to understand how firms may diversify their technologies for strategic reasons (Hansen & Nielsen, 2010), the timing in relation with production market competition (Milliou & Petrakis, 2011) and the adoption with involving disruption costs and learning by doing (Pérez & Ponce, 2015). In public economics literature technological gap and the consequent asymmetry in cost efficiency have been studied concerning optimal taxation (Dung, 1993), the welfare effects of subsidies in particular (Hamilton & Sandin, 1997) and trade policy instruments in general (Collie, 2006; Lahiri & Ono, 1997). Their analysis, however, mainly focus on homogenous firms.

Our work is also related to a list of articles on the effects of behavioral heterogeneity in oligopolistic markets. The coexistence and interaction of behaviorally heterogeneous agents have been studied between profit and relative profit maximizing firms (Riechmann, 2006), between simple and naïve behavior and more

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[1] See Bartel, Ichniowski and Shaw (2007)

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sophisticated strategies (Huang, 2003) and between optimizers and imitators (Schipper, 2009). More recently, quantity competition has been analyzed in oligopoly consisting of profit maximizers and firms following an alternative criterion (Chirco, Colombo, & Scrimitore, 2013) as well as of profit-maximizing firms and socially concerned firms (Kopel, Lamantia, & Szidarovszky, 2014).

Heterogenous oligopoly, however, especially the case where some firms behave strategically while others taking price parametrically, has been mostly studied under the assumption of identical cost structure industry wide. The issue of technological gaps, deliberately chosen or due to different qualities of inputs, has largely remained under-researched. Indeed, heterogeneous oligopoly is more relevant for the investigation of technological gaps where agents across strategy groups are potentially subject to different production technologies in terms of efficiency. This is a key distinctive feature of our work.

Accordingly, this paper adopts the framework of prior literature and makes two contributions. First, the main motivation we offer for the exercise is methodological: to derive, for the model adopted, certain results of general interest and applicability in the industrial organization literature. Considering an oligopoly model allowing for behavioral asymmetries, we assume that advanced Cournot firms equate their marginal revenue to marginal cost and simultaneously the remaining players equate their marginal cost to market price. Price-taking firms have been studied in many oligopoly literature such as the competitive fringe model in Stackelberg game (Asada & Semmler, 2004) and the cartel–fringe game (Benchekroun & Withagen, 2012). Increasingly the Walrasian behavior building on its central hypothesis that agents take prices parametrically has been studied in the evolutionary game theory literature since the seminal work of Vega-Redondo (1997). Firms adopting the price-taking strategy are found to outperform dynamic optimizer in a heterogeneous duopoly (Huang, 2010). The second contribution is to shed new lights on the incentive/disincentive for technological catching up. Particularly, we evaluate the effect of technological gap between the two strategic groups on output, profits, industry concentration and social welfare.

Our results reveal that widening technological gap could actually lead to higher profits for both the leader and laggard firms and that inferior technology is entirely possible to be adopted voluntarily by the backward firms. Also, backward firms deviating from technological leader in the industry could result in lower degree of market concentration and can be welfare improving. Deliberate distance from technological leader in the industry and the resultant preference over inferior technology turn out to be, in asymmetric oligopoly, a distinct possibility. Our results can explain why different technologies coexist in a homogenous goods market and shed some lights on the rationale of relatively inferior technology deliberately adopted by oligopolistic producers. Our model can provide some theoretical ground on the postponement in the diffusion of and the strategic timing of the adoption of new technologies.

The remainder of the paper is organized as follows. Section 2 introduces the model and elaborates the equilibrium analysis. Section 3 presents a numerical example which provides us with simple and empirically very plausible condition under which technological catching-up can be demotivating. Section 4 concludes.

2. Model and implications

Consider N firms each producing q^i, $i = 1, 2, \ldots, N$, of a homogeneous product with an inverse demand function $p = D(q^d)$ with $D' < 0$. For every $q^d = \Sigma_{i=1}^N q^i$ supplied to the market, D specifies the market-clearing price.

Firms are grouped into two categories: m firms are "Advanced" and $(N-m)$ firms are "Backward". Backward firms adopt less efficient technology and have no other market information (such as the market demand D, the composition of the industry, and the outputs of the rivals) except the price p. Therefore, they have to behave as price-takers. On the contrary, the remaining firms are advanced in the sense that they have more efficient technology and more market information so that they can adopt more advanced strategy through best-responding to the outputs of the backward.

The assumption of price-taking behavior of the backward firms can be justified in the following ways. When cost differentiation is allowed in heterogeneous oligopoly,[2] it is common to assume the price-takers to have cost disadvantage over the more sophisticated firms (Asada & Semmler, 2004), potentially because the latter enjoy better management or patented technology, or the benefit of economies of scale. Moreover, one may imagine that price-taking strategy being simpler than the Cournot one requires smaller cognitive cost to implement. For firms with inferior technology, the cognitive cost of finding the optimal strategy is not worth paying. In addition, it is possible that backward firms enter into an agreement to behave as price-takers. Such a collusive behavior is hard to detect and it may go unnoticed by antitrust authorities. Therefore, the equilibrium is determined jointly by each Cournot player's quantity best response curve and the supply curve of each price-taking firm.[3]

Assume that firms within their respective category adopt an identical convex technology. For the simplicity of comparison and discussion, we shall let $c_j(q) = C(q)$, with $C'' > 0$ for $j \in$ Advanced, and $c_j(q) = (1+\varepsilon)C(q)$, for $j \in$ Backward, where $\varepsilon \geq 0$ is the inefficiency parameter gauging the technological gap between the two groups.

Let x be the individual output of the backward firm and y be the output of the advanced firms. Then x is determined by $p = (1+\varepsilon)C'(x)$, that is,[4]

$$D((N-m)x + my) = (1+\varepsilon)C'(x) \tag{1}$$

while y is determined by $p + y(\mathrm{d}p/\mathrm{d}y) = C'(y)$, or, equivalently,

$$D(my + (N-m)x) + D'y = C'(y). \tag{2}$$

Eqs. (1) and (2) jointly determine a unique equilibrium $(\bar{x}(\varepsilon), \bar{y}(\varepsilon))$ with $\bar{x}(\varepsilon) > 0$ and $\bar{y}(\varepsilon) > 0$, so that

$$\begin{cases} D(\bar{q}(\varepsilon)) = (1+\varepsilon)C'(\bar{x}(\varepsilon)), \\ D(\bar{q}(\varepsilon)) = C'(\bar{y}(\varepsilon)) - \bar{y}D'(\bar{q}(\varepsilon)), \end{cases}$$

where $\bar{q}(\varepsilon) = (N-m)\bar{x}(\varepsilon) + m\bar{y}(\varepsilon)$.

Let $\bar{\pi}^x$ and $\bar{\pi}^y$ be the equilibrium profit for each firm in the respective category. Then we have

$$\begin{cases} \bar{\pi}^x(x, y) = \bar{x}D(\bar{q}) - (1+\varepsilon)C(\bar{x}), \\ \bar{\pi}^y(x, y) = \bar{y}D(\bar{q}) - C(\bar{y}). \end{cases}$$

[2] Without loss of generality, cost function here reflects overall cost structure of firms including the search cost for technology and the cognitive cost to implement the chosen strategy. Backward firms operate on less efficient production technology and as a result face a higher cost function (even after taking into account the cognitive cost for adopting the simpler price-taking strategy).

[3] The setting is different from the standard competitive fringe model characterized by strategic Cournot firms taking the supply functions of the fringe firms as given in deciding their own quantities. This essentially pertains to a Stackelberg model where the Cournot firms act as leaders while the fringe firms as followers. Our model instead builds on earlier literature on conjecture variation models, see for example Dung (1993) and Kamien and Schwartz (1983).

[4] Note that the backwards are assumed to be deficient in market information so that their only strategy is simple Cobweb strategy, that is, acting as price-takers with naive price expectations: $\hat{p}_{j,t} = p_{t-1}$ and planning its production based on $p_{t-1} = MC_t^j$, for $j = m+1, m+2, \ldots, N$. We thank the autonomous referee for pointing out this important clarification.