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Catching-up and falling behind: Effects of learning in an R&D differential game with spillovers☆

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ABSTRACT

In this paper we analyze the dynamics of an R&D differential game allowing for technological spillovers and sigmoid learning functions of multiproduct oligopolies. We demonstrate how the presence of learning together with spillovers may generate a rich set of outcomes, varying from constant leadership to catching-up and falling behind as well as from technology lock-in to a situation with a large number of high quality products. These types of outcomes are qualitatively different both from the single firm dynamics with learning and from the duopoly case with spillovers and without learning.

1. Introduction

Technical progress is a key factor of economic growth in market economies. Both the generation of new capital goods as well as the improvement of existing methods of production raise efficiency. Yet, it is still not clear whether existing large multi-product firms are more active in R&D, as it is claimed by Acemoglu and Cao (2015) for example, or whether new entrants invest more. It may be the case that monopolistic firms are prone to preserve existing technologies rather than inventing new ones, leading to a technology lock-in, as discussed in Krysiak (2011) and later on in Greiner and Bondarev (2017), while competition may stimulate the industry to move forward to new technologies. One important aspect in this transformation of the market is the role of technological leadership and the catching-up process of followers.

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In economics, the question of which factors determine the leadership of certain firms and the catch-up process of other competing firms has been analyzed for quite a long time (see e.g. Fagerberg and Godinho, 2005). Besides sound institutional factors in an economy, such as a functioning bureaucracy and a reliable legal system, human capital and innovations are of vital importance for initially lagging firms to be successful in the catch-up process (cf. Freeman and Soete, 1997 or Freeman and Loica, 2001). For example, during most of the 19th century, firms in the United Kingdom represented the economic and technological leaders of the capitalist world. However, in the 2nd half of the century both the United States and Germany started to catch-up by not only imitating the leader, but, by introducing new ways of production and by improving existing technologies. For example, in Germany firms of the chemical and industrial sector were particularly successful in this process and took over the leadership in some fields. After the 2nd World War, Japanese firms succeeded to catch-up to the leading firms of the Western hemisphere, in particular in the automobile sector. Further, the innovations in Japan did not only benefit Japan, but, they diffused to firms in other economies, especially in the United States, and raised the productivity there. This shows that there exist spillovers between firms and that those firms that have been overtaken do not necessarily vanish. Rather, they are capable to catch-up to the new leader, and, possibly, to take over the lead again.

Further, there is additional evidence that spillovers are a relevant phenomenon. Thus, empirical studies stress the importance of spillovers for an industry, like Henderson (1993) and Bos et al. (2013). The first paper finds that leading firms invest more into incremental R&D while followers (new entrants) concentrate on fundamental discoveries and the second contribution analyzes the non-monotonicity of relationships across types of innovations over the industry life-cycle. The role of spillovers in R&D has been empirically studied in Henderson and Cockburn (1996), Jaffe (1986), Bernstein and Nadiri (1989) and recently in Bloom et al. (2013), among others, where an ambiguous effect of spillovers with respect to the generation of innovations has been found.

These considerations demonstrate that the process of catching-up and falling behind is not only of academic interest, but, has a large empirical relevance, too. Therefore, in this paper we study the question of which factors determine the catch-up process, where we pay particular attention to the role of spillovers and learning. To do so, we build a highly stylized model of firms competing in an oligopolistic market to gain insight into the determinants of that process. In particular, this paper deals with the question of whether a constant technological leadership is beneficial for the generation of new technologies or whether the taking over by an initial follower can speed up the introduction of new technologies. A closely related question is whether the competition in R&D is beneficial in terms of helping to avoid a technology lock-in and what the limits for these benefits are.

To answer these questions we analyze a model of innovating multiple-product firms with doubly-differentiated innovations (vertical and horizontal), where we allow for heterogeneous innovations and where we take into consideration R&D spillovers. The leader is defined as the firm with the highest developed technology i, but, the leadership may change over time,[1] either temporarily or permanently. We obtain three qualitatively different scenarios: a permanent technological leadership of one of the companies, a catching-up by the initial follower with a constant leadership afterwards, or a temporary loss of the leading position. The outcome depends on the technological distance between the leader and the followers: once the distance is high, the leader is permanent as in baby food industry with the permanent Nestle leadership, for example. When the distance is lower, there may be a catching-up situation as it happened with computer hardware manufacturing, which experienced the loss of AMD leadership that has not been recovered (yet). The third type of dynamics may happen if the distance is non-monotonic across applications and the follower can have an advantage in some specific range of technologies, but not in others. An example for this type of dynamics is provided by Apple that started off as a clear technology leader at the end of the 1970s, fell back in the 1990s, returned and became again the leader in the 2000s.

Problems of market dynamics and oligopoly dynamics have been studied by Carl Chiarella, too, who contributed a lot to the field of economics and finance. Especially in the early stage of his career he analyzed problems of market dynamics and oligopoly dynamics. In Chiarella et al. (1989) the authors develop a leader-follower model that analyzes the interaction of R&D, the leakage of knowledge and product pricing. The leader invests in R&D and sets the product price. Newly developed technologies become available to the follower with a time delay. The paper, then, derives the optimal trajectories and derives several results with respect to comparative statics. The paper by Chiarella (1991) studies a Cournot oligopoly model with time delays in production and information. It is demonstrated that a Hopf bifurcation can occur giving rise to limit cycles and the conditions leading to that phenomenon are characterized. Imperfect competition on the product and factor markets is allowed for in the model by Chiarella and Okuguchi (1995). There, the existence and stability of a Cournot duopoly with those characteristics are analyzed and it is demonstrated that antisymmetric equilibria may exist and conditions for local and global stability are derived. The effects of nonlinearities in a Cournot oligopoly model with an unstable equilibrium are analyzed in Chiarella and Khomin (1996). The authors discuss types of nonlinearities and introduce time lags in production and information which serve as bifurcation parameters. Using the Hopf bifurcation theorem, it is proven that stable limit cycles can arise and the conditions giving rise to cycles are identified. In another contribution, Chiarella and Szidarovszky (2004) analyze the effects of information on the price function in dynamic oligopolies. It is assumed that firms experience time lags in obtaining and implementing information on the price and on the output. It turns out that time lags

[1] this notion of leader has nothing in common with the Stackelberg notion: all firms act simultaneously and the leader does not have any advantage except for a higher technological level.

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