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Open Innovation in a dynamic Cournot duopoly

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ABSTRACT

In recent years Open Innovation (OI) processes have been receiving growing attention from the empirical and theoretical economic literature, where a debate is taking place on the aspects of complementarity or substitutability between internal R&D and OI spillover. By means of a differential game approach, we analyze the case of substitutability in an OI setup in a Cournot duopoly where knowledge spillovers are endogenously determined via the R&D process. The game produces multiple steady states, allowing for an asymmetric solution where a firm may trade off the R&D investment against information absorption from the rival. The technical analysis and the numerical simulations point out that the firm which commits to a higher level of OI absorption produces a smaller output and enjoys higher profits than its rival.

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1. Introduction

According to Chesbrough (2003), the economic system is entering a new era of Open Innovation (OI), where OI is defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively". This fact is a logical consequence of a fast growing and highly competitive market for new technologies. At this rate of growth, the companies' internal resources are not sufficient to meet the new challenges, and they have to access external sources. What drives firms towards OI is the fact that many companies are obliged to innovate and develop new products under extremely tough time and resource constraints in order to stay in the market and keep being competitive.

OI is vital for companies whose products have short life cycles (for example software and consumer electronics) and extremely demanding criteria regarding quality, price and customers' expectations. Specifically, the typical example of OI is the Open Source software: Linux, Unix, Mozilla, OpenOffice, Android are products whose source code has been partially or completely released (for an exhaustive overview of the economics of Open Source and on its technological aspects, see Lerner and Tirole, 2002, and West and Gallagher, 2006). Open Source developed by Information Technology firms may be a convenient strategy, when companies expect to boost their profits in a complementary segment, or when they are so small that they cannot compete commercially in the primary segment (Lerner and Tirole, 2002).

The complexity and diversity of the knowledge structure, like nanotechnologies and biotechnologies, are another important factor. As long as "not all smart people work for you" (Chesbrough, 2003), there is an increasingly dispersed distribution of useful knowledge in companies of all sizes. The amount of available information is heterogeneously spread and companies cannot access and monitor all necessary networks. Those networks are built on several factors, including governmental and private organizations, academic research, synthetic knowledge, know-how and highly specialized knowledge based on experience and interaction among the agents. Hence, OI provides an access to these networks. Thus, in a fast developing and expanding environment, relying on the Closed Innovation approach is both insufficient and risky.

The OI policy allows the company to use external technologies (Spithoven et al., 2011) and share its own knowledge with outside partners at a strictly managed and controlled level. The company boundaries become "permeable" (Mortara et al., 2009). The process of learning, accumulation of outside knowledge and competence enables the company to be not only more innovative, but also innovate at a higher speed. It creates linkages among companies that stimulate the sharing of ideas, technology and experience. These strategies, as presented by Monica Beltrametti, Vice President of the Xerox Research Center Europe (XRCE) at Grenoble Innovation Fair (GIF) on October 2009, help share the risk, and reduce costs by using more suppliers. This also opens the way to new markets and explorations (ideas from new external participants, such as governmental organizations, universities, other large companies and individual representatives).

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Furthermore, Open Innovation is an innovation in itself (Mortara et al., 2009). It stimulates innovation by distributing the cost and risk, offering access to new contact networks through "intermediaries" (Mortara, 2010) and information pools, and also internalizes the unintended byproducts of innovation process, spillovers (Bogers, 2011). A recent study on the underlying factors affecting the degree of openness of a firm from a strategic point of view is provided by Drechsler and Natter (2012). An accurate description of the various kinds of OI and on the way it has been treated in literature can be found in Dahlander and Gann (2010). Assuming the distinction between inbound and outbound OI, they identify sourcing and acquiring as the typical inbound processes and revealing and selling as the typical outbound processes and investigate the advantages and the disadvantages of each form of openness.

The Closed Innovation model based on the traditional patent system discards unintended or irrelevant research results; however, it has long been considered as a necessary cost for enhancing technical progress. Conversely, the OI policy allows the company to sell those products that do not meet the firm's capacity and development possibilities (in form of IP licenses) to other companies (Chesbrough, 2003; Chesbrough et al., 2006). For example, in bio-pharmaceutical industry firms outlicense for profit in different stages of R&D process, because they endogenously decide how much of innovation they want to disclose or sell (Bianchi et al., 2011). If observed from this new angle, the firm turns out to have two functions: one is learning from the environment and the other is constructing it by sharing its own knowledge via a systematic spillover flow. Hence, no proof exists that OI generates less spillovers. The company must spend in order to innovate, it must create and achieve itself the new technologies or find them on the market in the opposite case. Thus, there should be a balance between the level of internal R&D and external knowledge resources accrued by the firms. Otherwise, due to spillover's negative effect, that reduces the gains, the firms have a lower investment level than socially desired (as in Arrow, 1962, *inter alia*). In other cases firms may not take into account the positive level their spillovers have on other firms' R&D and vice versa, leading again to suboptimal level of R&D (Romer, 1990). On the other hand, firms may be trapped into patent racing and overinvest, thus significantly affecting their profit levels. Moreover, they can disclose too much internal information by adopting a purely Open Innovation approach (Enkel et al., 2009).

An important issue about OI is the ongoing debate on the complementarity or substitutability between the internal and external knowledge used for innovation in a given company. In order to maximize the profits and achieve better results, the company should be able to efficiently scan the environment and correctly assess the degree of complementarity between its R&D program and externally available technology in order to take advantage from the OI policy (Vanhaverbeke et al., 2008). This aspect of a firm's overall strategy can be thought of as a dynamic capability which is built over time (Helfat et al., 2007). Despite these arguments, there are scholars proving that, strategically, some firms rely on substitutability rather than complementarity, due to higher costs of the latter, industry specific qualities or budget constraints.

Moreover, it is worth stressing that OI can be achieved through different routes. One possibility is that the firm implements the policy as a "conscious" movement due to its internal necessities (Mortara et al., 2009). Another possibility is that firms are pushed towards OI by some external factors, like globalization, knowledge-intensive environment, markets, or customer preferences. What happens if the firms are able to optimally determine the spillover delivered to others in the industry, and – in turn – rationally grab the spillovers created by other firms? The effect is an increase in their gains, and a decrease in unnecessary competitiveness. According to Jaffe (1986), who analyzed the relevance of external R&D to individual companies, spillovers have a positive impact on productivity of own R&D, and a negative effect on competitiveness. This effect is confirmed in a recent empirical paper by Czarnitzki and Kraft (2012).

Since OI has been studied theoretically and empirically in the latest two decades, some models have already appeared in the economic literature, especially concerning Open Source software. The most common frameworks have been the static oligopoly games by far. Some aspects of technology transfers and differentiated Cournot duopolies leading to asymmetric equilibrium structures have been investigated by Zanchettin (2006), whereas Li and Ji (2010) have focused on the characteristics of cost-reducing innovation. Modica (2012) has proposed a model of Open Source development as a two-stage oligopoly game. Another two-stage game is the one constructed by Llanes and de Elejalde (2013) between Open Source and proprietary firms. To the best of our knowledge, one of the very few contributions on OI building on a dynamic model has been conceived by Caulkins et al. (2013), where the authors characterize the optimal strategy of a firm when it has to choose between proprietary and Open Source software. From a technical viewpoint, their model is an optimal control problem for a firm in the market subject to the evolutionary dynamics of the quality of its product. Their analysis focuses on the crucial role of R&D costs, and intends to explain when it is convenient to open the source code for the firm.

But why does a large company choose an OI policy? A very relevant example of large IT company which committed to OI development strategies is IBM. In 1993 IBM agreed to sell its industry-leading $2\frac{1}{2}$-inch drives to Apple, which was one of its direct competitors, to use inside its PowerBook laptop computers (see Chesbrough, 2003). In 1999, IBM announced support for Linux, starting to invest financial and technical resources to foster growth, development and use of Linux Open Source technology. In particular, IBM simply explains its commitment to Open Source technology by listing some clear motivations (see the Section 'Linux and IBM' in the IBM website: http://www-03.ibm.com/linux/): 'IBM established the Linux Technology Center (LTC) as the primary vehicle to participate in the Linux community. IBM and the LTC have established four goals for participation in the Linux community: make Linux better, expand Linux's reach for new workloads, enable IBM products to operate with Linux, increase collaboration with customers to innovate in ways IBM cannot do by itself'.

In this paper, we will take into account a duopoly allowing for both symmetric and asymmetric optimal strategies where the two firms engage in a Cournot competition to maximize their discounted payoff flows over an infinite horizon. In our setup, the firms' strategic variables are the quantities and the levels of R&D efforts, whereas the state variables are the marginal costs of production and the levels of positive technological spillover spreading from a firm to its rival. Namely, we will look upon OI for one player as depending on her opponent's development of R&D, as if OI was the fraction of the research she takes or buys from outside, then resulting in a sort of substitute (not complement) with respect to her own R&D. Consequently, we will focus on the aspects of substitutability of OI rather than complementarity of OI. In this respect, Spithoven et al. (2012, p. 240) state that 'However, empirical evidence does not always support the idea of complementarity between internal and external R&D. Based on a cross-section of the Dutch manufacturing firms, Audretsch et al. (1996) reported a substitution effect of external R&D activity in low and medium technology industries (the reverse was true in high-tech industries)'. Also Fu (2012) finds that the complementarity between internal R&D and OI is not always feasible, being too costly. It is relevant to remark that OI is not totally free, i.e. we will take into account an appropriation cost of external innovation for the firms.[1]

The model we adopt is a differential game, which has never been employed in a similar framework, because the above literature either

[1] This aspect is confirmed by some empirical papers such as Lokshin et al. (2008) and Fu (2012), which have analyzed the impact of internal and external R&D on productivity and incentives for further innovation. In particular, Lokshin et al. (2008) have examined the data on a 6-year panel of Dutch manufacturing firms, finding that the costs of appropriation of external R&D were definitely smaller than the costs of development of internal R&D.

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