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THE IMPACT OF PATENTS AND R&D COOPERATION ON R&D INVESTMENTS IN A DIFFERENTIATED GOODS INDUSTRY

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Abstract

In this paper, we consider the impact of patents and R&D cooperation on R&D investments in the oligopolistic industry with differentiated products. Four types of firms' conduct are investigated: R&D competition without patents, R&D competition with patent protection, R&D cooperation, and the full industry cooperation. The obtained results suggest that patents do not necessarily promote R&D investments due to the existence of so called tournament effects. R&D cooperation stimulates R&D investments, but R&D cooperation provides sufficient incentives to create a full industry cartel. Such a cartel works to the detriment of consumers. Our analysis led us to the conclusion that for a relatively low level of R&D spillovers, the policy-makers should promote R&D competition without patent protection among oligopolistic firms. For a relatively high level of R&D spillovers, R&D cooperation enhances innovation, but the regulator should monitor the market for probable collusion.

Keywords: *research and development, investments, patents, cooperation, differentiated goods*

JEL classification code: *O3*

INTRODUCTION

One of the fundamental tasks of the modern innovation policy is to promote private R&D investments (cf., e.g., Becker 2015; Pejic-Bach et al. 2015; Schot and Steinmueller 2018; Mahmutaj and Krasniqi 2020). The private R&D investments play a critical role in explaining economic growth (Becker 2015). The latter statement is supported by a large body of empirical and theoretical literature (see, e.g., Romer 1986; Grossman and Helpman 1991; Howitt and Aghion 1998; Kafouros 2005; O'Mahony and Vecchi 2009; Bravo-Ortega and Marin 2011; Bezdrob and Šunje 2014; Becker 2015). Promoting private R&D investments is though a tricky task, since the private R&D constitutes a public goods' problem (Nelson 1959; Arrow 1962; Becker 2015). The private R&D is non-rival and non-excludable, thus leading to the discrepancy in the private and social rate of return. The firms investing in R&D are not capable of appropriating all the returns from the

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investments which generate the knowledge spillovers (externalities) to the benefit of others (competitors, suppliers, buyers, universities, to name a few). The discrepancy in the private and social rate of return results in the private underinvestment in R&D. Thus, the public policy finds it both necessary and beneficial to promote private investments in R&D.

Based on Czarnitzki and Toole (2006), Lokshin and Mohnen (2012), Becker (2015), Schot and Steinmueller (2018), Bloom, van Reenen and Williams (2019), and Stojčić, Srhoj and Coad (2020), the modern innovation policy offers the following instruments to promote the private R&D investments (for a detailed presentation, see the next section):

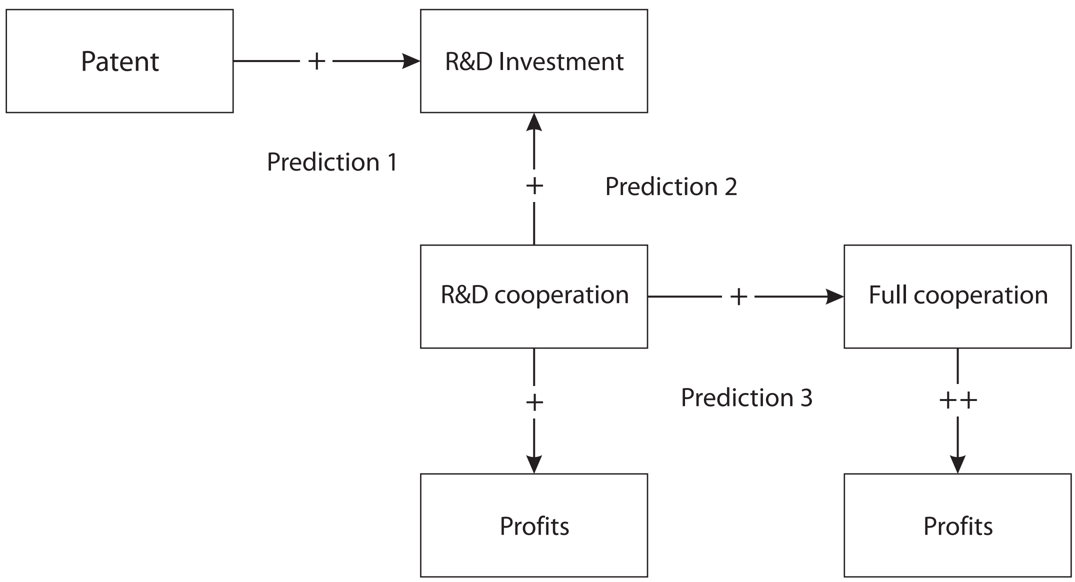
1. R&D tax credits and direct grants or subsidies (including cost-sharing arrangements, tax exemptions, provision of financial guarantees),
2. support of the university research and technology transfer from public labs,
3. patents,
4. R&D cooperation,
5. public procurement for innovation.

In this paper, we focus on the two instruments of innovation policy, i.e., patent protection and R&D cooperation. The reason for placing the emphasis on those two instruments is the current economic debate on the interactions between patents and cooperative R&D agreements, and in particular, on their complementarity or substitutability (cf., e.g., Penin 2005; 2012; Somaya 2012; Boldrin and Levine 2013; Comino et al. 2019).

The primary aim of this paper is to investigate the impact of patents and R&D cooperation on R&D investments made by firms. Since most of R&D investments refer to product markets with differentiated goods (Flath 2012; Rant and Černe 2017; Karbowski 2019), we consider a differentiated goods industry. In particular, we compare the R&D investments made by firms under the following market structures: R&D competition without patents, R&D competition with patent protection, R&D cooperation, and full industry cooperation. As a secondary goal, we investigate the firms' incentives to follow patenting strategy or cooperative strategy. To this end, we compute the firms' profits corresponding to the four market structures mentioned above.

Based on the reviewed literature (for a detailed presentation, see the next section), we formulate the following predictions (cf., figure 1). First, we expect that in a differentiated goods industry, patents augment R&D investments made by firms. Second, we expect that in a differentiated goods industry, R&D cooperation increases R&D investments undertaken by firms. Third, we expect that in a differentiated goods industry, firms' profits are the highest when the full industry cooperation (cartelization) takes place.

Figure 1. The conceptual model and theoretical predictions.



Source: own elaboration.
"+" – positive impact
"++" – stronger than "+" positive impact

The paper is organized as follows. After the literature review, we consider the reference case of R&D competition without patents. Then, we investigate the scenario of R&D competition with patent protection. Next, we analyze R&D cooperation, and further, we consider a case of full industry cooperation (cartelization). The subsequent section discusses the obtained results. Conclusions follow and close the paper.

LITERATURE REVIEW

The modern innovation policy offers supply-side (push) and demand-side (pull) instruments (Petrin 2018) to promote private R&D investments. To the first group belong R&D tax credits and direct subsidies, support of the university research and technology transfer, patents, and R&D cooperation. Public procurement for innovation constitutes, in turn, the flagship demand-side instrument.

R&D tax credits and direct subsidies (Besley and Suzumura 1992; Bagwell and Staiger 1994) belong to the public finance tools which allow to secure the economic activity that generates positive externalities. The "older" economic literature (literature published prior to 2000) arrived at the conclusion that R&D tax credits as a supply-side (push) policy instrument (Petrin 2018) exert a significant positive impact on private R&D investments (see, Hall and van Reenen 2000, for a review), though the strength of that impact exhibits a relatively high variability and depends on the strategic substitutability of outputs and cost-reducing R&D investments (Besley and Suzumura 1992). Bagwell and Staiger (1994) show that when R&D reduces costs of production, there exists a strategic basis for R&D subsidies and a corrective incentive to tax R&D. As Leahy and Neary (1997) observe, R&D subsidies are justified except when R&D spillovers are low and firms' actions are strategic substitutes.

The "newer" literature confirms the positive empirical relationship between the R&D tax credits and private R&D investments (Baghana and Mohnen 2009; Czarnitzki et al. 2011; Hodžić 2012; Mulkay and Mairesse 2013; Becker 2015; Chang 2018), and is unanimous in assessing the strength of the above effect. The reported negative elasticity of private R&D investment with respect to the user cost is around unity. As regards the impact of direct subsidies on private R&D investment, the relevant literature did not reach a compromise. Some of the existing studies report a negative relationship between the direct subsidy and private R&D investment (the crowding out effect), cf., e.g., David et al. 2000; Garcia-Quevedo 2004; Becker 2015. The other reports point to the positive relationship between direct subsidies and private R&D investments (the additionality effect), cf., e.g., Duguet 2004; Carboni 2011; Bloch and Graversen 2012; Becker 2015.

Another supply-side instrument, the university research and technology transfer, can effectively support private R&D. As Nelson (1986) observed, the university research rarely generates new technologies, but often it enhances technological opportunities and the productivity of private R&D (Becker 2015). There is a large body of empirical literature that reports the positive impact of the university research on the private R&D investments (cf., e.g., Jaffe 1989; Woodward et al. 2006; Karlsson and Andersson 2009; Abramovsky and Simpson 2011; Becker 2015; Scandura 2016; Guerrero et al. 2019). As Becker (2015) notes, improving the university research and facilitating spillovers to the private sector effectively raise R&D investments made by firms. The knowledge spillovers from universities play a critical role in the development of high-tech industries. The government via the targeted support of the university research can thus speed up the progress in the selected high-tech industries. Such a policy can bring about more breakthrough innovations (Harryson et al. 2007).

As Czarnitzki and Toole (2006) observe, patents grant inventors temporary monopoly rights which allow the inventors to appropriate a greater share of the returns resulting from the invention which generates positive knowledge externalities. The patent mechanism reduces the discrepancy in the private and social rate of return from the R&D investment, thus patents are believed to directly promote and push private innovation (see, Nordhaus 1969 or Mazzoleni and Nelson 1998, for a wider discussion). On the other hand, some economists suggest that patent protection can in fact reduce private R&D due to the existence of so called tournament effects (Chowdhury 2005). Tournament effect adversely influences R&D incentives if firms simultaneously undertake similar activities leading to the given patent (Che and Yang 2009). Delbono and Denicolo (1991) show in a one-shot non-cooperative game that increasing rivalry in a patent race can decrease the individual R&D investments made by oligopolistic firms and lead to the underinvestment from the social welfare viewpoint.

Innovation policy-makers can promote R&D cooperation (a supply-side instrument) between firms to stimulate private R&D investments (Cassiman 2000; Barajas et al. 2012). As d'Aspremont and Jacquemin (1988) show, firm's R&D investments are higher under R&D cooperation compared with R&D competition, if the level of knowledge spillovers in the industry is sufficiently large. Kamien and co-authors (1992), and

Kamien and Zang (2000) confirm in a more general model of oligopoly that firm's R&D investments under R&D cooperation dominate those under R&D competition, if the level of spillovers is large enough. The latter result has been also confirmed empirically, see, e.g., Becker and Dietz (2004) or Aschhoff and Schmidt (2008). In the presence of positive knowledge externalities, the higher appropriability of R&D returns under cooperative R&D compared with the competitive R&D enhances corporate R&D investments and innovation under R&D cooperation compared with R&D competition (Czarnitzki et al. 2007; Becker 2015; Belderbos et al. 2018). Petit and Tolwinski (1999) show that the creation of R&D cooperation may be beneficial both from a private and social welfare point of view. The drawback of R&D cooperation is however the risk that R&D cooperation can provide sufficiently strong incentives to form a cartel on the final product market (R&D cooperation can be a stepping stone to the full industry cartel, cf., Martin 2006; Miyagiwa 2009). If R&D spillovers are maximal, collusive market outcomes become very likely (Kräkel 2004).

Public procurement for innovation (PPI) is a demand-side (pull) instrument (Petrin 2018; Stojčić et al. 2020) which can effectively reduce the costs of learning and product enhancing while offering scale economies to firms. As a result, firms can substantially reduce their costs of developing and commercialising new products or technologies (Stojčić et al. 2020). Further, PPI can help governments increase a demand for innovations which address societal needs and grand challenges (e.g., climate change, energy efficiency, food and health, sustainable transport; Stojčić et al. 2020).

R&D COMPETITION

We consider an industry composed of two companies, denoted 1 and 2. They manufacture q_1 and q_2 units of a heterogeneous product, respectively. The market demand for the product is given by the inverse demand function in the following form:

$$p_i = a - q_i - sq_j \ , \tag{1}$$

where p_i denotes the market price of the final good offered by firm i, q_i is the volume produced by firm i, a is the demand intercept (the larger value corresponds with the larger product market), and $s\ (0 \leq s \leq 1)$ is the substitutability parameter. Observe that both goods are perfect substitutes when $s = 1$, and the firms become monopolists when $s = 0$.

The total manufacturing cost of each company is characterized by the following quadratic function (the justification of such specification can be found, e.g., in Hattori and Tanaka 2019):

$$\frac{q_i^2}{c}, \tag{2}$$

where c is a given parameter of an initial efficiency of firm i. It is assumed that the entry barriers to the industry are too high for new enterprises to enter.

The model proceeds in two stages, as in Besley and Suzumura (1992). In the first, R&D, stage, both companies simultaneously and independently decide about their levels of R&D investments, x_i. These decisions affect the functions of total manufacturing costs of each firm. The costs of R&D investments have a form of quadratic function:

$$\gamma \frac{x_i^2}{2}, \tag{3}$$

where y ($y > 0$) is a given parameter. In the second, product market, stage, the companies compete in the final product market according to the Cournot model.

First, we consider the case in which the invention resulting from the R&D works is not protected by the patent (R&D competition without patents). When both firms invest in R&D, the cost of manufacturing for firm i is given by the following function:

$$C_i(q_i, x_i, x_j) = \frac{q_i^2}{c + x_i + \beta x_j}, \tag{4}$$

where x_i denotes the amount of R&D investments made by the company i, and x_j denotes the amount of R&D investments made by the competitor, firm j. Parameter $\beta\ (0 \leq \beta \leq 1)$ determines the size of R&D spillovers, i.e., the benefits for a given company obtained as a result of research undertaken by the competitor.

The profit of firm i may be written in the following form:

$$\pi_i = \left(a - q_i - sq_j\right)q_i - \frac{q_i^2}{c+x_i+\beta x_j} - \gamma \frac{x_i^2}{2}. \tag{5}$$

The first order conditions with respect to q_i generate the level of output that maximizes the profit of company i:

$$q_i = \frac{a\left(2+\frac{2}{c+\beta x_1+x_2}-s\right)}{4\left(1+\frac{1}{c+\beta x_1+x_2}\right)\left(1+\frac{1}{c+x_1+\beta x_2}\right)-s^2}. \tag{6}$$

Observe that the production levels q_1 and q_2 given by (6) constitute the Cournot-Nash equilibrium for given levels of R&D investments, x_1 and x_2.

After substituting (6) into (5), we obtain the profits of each firm, π_1 and π_2, as functions of R&D investments, x_1 and x_2:

$$\pi_i(x_1, x_2) \qquad (i = 1, 2). \tag{7}$$

In the first stage, when firms simultaneously decide about their R&D activities, the Nash equilibrium strategies are obtained as a solution to the following set of two equations with two unknowns, x_1 and x_2:

$$\frac{\partial \pi_i}{\partial x_i} = 0 \qquad (i = 1, 2). \tag{8}$$

Denote the solution to the above system by x_1^* and x_2^*. By substituting x_i^* for x_i into (6), and (7), we obtain the equilibrium output levels, q_i^*, and the equilibrium profits, π_i^*. Since we consider a symmetric equilibrium, we have $x_1^* = x_2^*$, $q_1^* = q_2^*$, and $\pi_1^* = \pi_2^*$.

We use numerical analysis in order to show possibilities of certain outcomes. In this paper, we will restrict our considerations to the case when three parameters of the model are: a = 100, c = 1, y = 3. The results of the calculations for s = 0.5 and various levels of parameter β are given in table 1.

Table 1. R&D competition – the case of no patents for a = 100, c = 1, y = 3, s = 0.5, and $\beta \in [0,1]$

β	x_i^*	q_i^*	p_i^*	π_i^*
0.0	7.22795	36.4555	45.3168	1412.16
0.1	6.70392	36.5120	45.2320	1424.90
0.2	6.24431	36.5566	45.1651	1435.25
0.3	5.83592	36.5909	45.1136	1443.74
0.4	5.46894	36.6161	45.0759	1450.76
0.5	5.13587	36.6329	45.0506	1456.59
0.6	4.83085	36.6420	45.0371	1461.43
0.7	4.54923	36.6435	45.0348	1465.44
0.8	4.28724	36.6376	45.0436	1468.73
0.9	4.04175	36.6242	45.0637	1471.37
1.0	3.81013	36.6031	45.0954	1473.43

Source: own calculations

From table 1, it follows that the R&D investments of each firm decline with the growing scale of R&D spillovers. The supply of the final product achieves its maximum for the parameter β = 0.7, which results in the lowest level of the market price. However, the profits of each firm are higher when the extent of R&D externalities is greater.

Now, we look at the effect of changes in the substitutability (parameter s) on the behavior of firms. Table 2 reports the Cournot equilibrium for various levels of s, and the R&D spillover parameter β = 0.3.

Table 2. R&D competition – the case of no patents for a = 100, c = 1, y = 3, β = 0.3, and $s \in [0,1]$

s	x_i^*	q_i^*	p_i^*	π_i^*
0.0	6.90939	45.4472	54.5528	2200.75
0.1	6.62133	43.3244	52.3431	2006.61
0.2	6.37354	41.4012	50.3185	1837.72
0.3	6.16202	39.6517	48.4528	1689.79
0.4	5.98364	38.0543	46.7240	1559.38
0.5	5.83592	36.5909	45.1136	1443.74
0.6	5.71702	35.2462	43.6061	1340.59
0.7	5.62568	34.0069	42.1882	1248.11
0.8	5.56123	32.8620	40.8483	1164.75
0.9	5.52355	31.8018	39.5767	1089.22
1.0	5.51329	30.8178	38.3644	1020.43

Source: own calculations

From table 2, it follows that the size of R&D investments declines monotonically together with an increasing degree of substitutability (increasing parameter s).

Together with a decline in product differentiation, we observe a decreasing level of profits earned by the duopolists. The highest profits are obtained when product differentiation is maximal, i.e., s = 0; the lowest profits are observed when products are homogenous, i.e., s = 1. Also, the level of prices is lowest when the product differentiation is minimized.

Next, we consider R&D competition with patent protection. A patent obtained by firm i reduces its manufacturing costs according to the formula (4). However, a patent obtained by firm j (the competitor), does not allow firm i to use the patented technology, and firm i manufactures at the costs given by formula (2). Since the firms are identical, we assume that the chance of patenting by each of them is 0.5.

Thus, in the case with patent protection, the expected profit of a duopolist i is given as:

$$\pi_i^e = pq_i - \gamma \frac{x_i^2}{2} - \left(\frac{1}{c + x_i + \beta x_j} + \frac{1}{c}\right) \frac{q_i^2}{2}. \tag{9}$$

The optimal level of supply by firm i is:

$$q_i = \frac{a\left(2 + \frac{2}{c} + \frac{2}{c + \beta x_1 + x_2} - s\right)}{4\left(1 + \frac{1}{c} + \frac{1}{c + \beta x_1 + x_2}\right)\left(1 + \frac{1}{c} + \frac{1}{c + x_1 + \beta x_2}\right) - s^2}. \tag{10}$$

After substituting (10) to the expression (9), we obtain the equilibrium expected profit of firm i (this profit is a function of R&D investments). The optimal levels of R&D investment are calculated as a solution to the following set of equations: $\frac{\partial \pi_i^e}{\partial x_i} = 0 \ (i = 1, 2)$.

Denote this solution as $\hat{x}_1$ and $\hat{x}_2$. The optimal levels of production are denoted as $\hat{q}_1$ and $\hat{q}_2$, and optimal levels of expected profits are called $\hat{\pi}_1^e$ and $\hat{\pi}_2^e$. Since our firms are identical, we consider a symmetric case, $\hat{x}_1 = \hat{x}_2$, $\hat{q}_1 = \hat{q}_2$ and $\hat{\pi}_1^e = \hat{\pi}_2^e$.

Table 3 provides the results of numerical analysis for the case with patent protection and for the previously selected set of parameter values.

Table 3. R&D competition – the case of patent protection for a = 100, c = 1, y = 3, s = 0.5, and $\beta \in [0,1]$

β	$\hat{x}_i$	$\hat{q}_i$	$\hat{p}_i$	$\hat{\pi}_i^e$
0.0	4.61019	20.5910	69.1135	891.671
0.1	4.31294	20.6263	69.0605	897.052
0.2	4.05374	20.6567	69.0149	901.512
0.3	3.82500	20.6831	68.9754	905.261
0.4	3.62105	20.7060	68.9410	908.447
0.5	3.43760	20.7260	68.9110	911.181
0.6	3.27130	20.7434	68.8849	913.545
0.7	3.11951	20.7585	68.8622	915.600
0.8	2.98012	20.7716	68.8425	917.395
0.9	2.85140	20.7829	68.8256	918.968
1.0	2.73195	20.7926	68.8111	920.350

Source: own calculations

It follows from table 3 that the R&D investments decline with the growing scale of R&D spillovers. This result is similar to the case of no patent protection. However, the increasing size of R&D externalities induces here the larger supply of the final product and lower level of the market price, which is different from the case of no patent protection. The resulting profits of firms are higher when the extent of R&D externalities is greater.

Next, we analyze the impact of changes in the substitutability parameter on the behavior of firms. The Cournot equilibrium for the R&D spillover parameter β = 0.3, and various levels of s are shown in table 4.

Based on table 4, the level of R&D investments is declining when the product differentiation becomes lower (increasing parameter s). A decline in product differentiation reduces the supply and the profits of companies. It is not surprising that the firms enjoy the highest profits when product differentiation is maximal, i.e., s = 0. The consumers enjoy the lowest prices when the product differentiation is minimized, i.e., s = 1. These results are similar to the case of no patent protection.

Table 4. R&D competition – the case of patent protection for a = 100, c = 1, y = 3, s = 0.5, β =0.3 and $s \in [0,1]$

s	$\hat{x}_i$	$\hat{q}_i$	$\hat{p}_i$	$\hat{\pi}_i^e$
0.0	4.23890	23.2170	76.7830	1133.900
0.1	4.14300	22.6593	75.0747	1081.550
0.2	4.05402	22.1289	73.4453	1032.830
0.3	3.97157	21.6239	71.8889	987.396
0.4	3.89533	21.1425	70.4006	944.962
0.5	3.82500	20.6831	68.9754	905.261
0.6	3.76031	20.2443	67.6090	868.057
0.7	3.70103	19.8249	66.2976	833.140
0.8	3.64696	19.4236	65.0375	800.320
0.9	3.59791	19.0393	63.8252	769.426
1.0	3.55373	18.6711	62.6579	740.305

Source: own calculations

R&D COOPERATION

In this section, we consider the cooperation of firms in the R&D stage, but not on the final product market (the case of R&D cooperation, often called the R&D cartel, see, e.g., Kamien et al. 1992; Kamien and Zang 2000; Karbowski 2019). The firms are assumed to behave non-cooperatively as Cournot players in the final product market. When deciding about the levels of R&D investments, the companies maximize the joint profit of the R&D cartel, i.e., $\pi(x_1, x_2) = \pi_1 + \pi_2$. Since we focus on the symmetric equilibria, the optimal level of R&D investment of an individual firm amounts to $\tilde{x}_1 = \tilde{x}_2$, the optimal supply of the final product equals $\tilde{q}_1 = \tilde{q}_2$, the optimal market price equals $\tilde{p}_1 = \tilde{p}_2$, and the optimal level of profit is $\tilde{\pi}_1 = \tilde{\pi}_2$.

Table 5 illustrates the results of a numerical analysis in the case of an R&D cartel for the previously selected set of parameter values.

It follows from table 5 that an increasing level of R&D spillovers causes a decline of R&D investments and of the price of the final product, but induces an increase of supply and profits of firms. This result is similar to the case of R&D competition under patent protection.

Table 5. R&D cartel – equilibrium for a = 100, c = 1, y = 3, s = 0.5, and $\beta \in [0,1]$

β	$\tilde{x}_i$	$\tilde{q}_i$	$\tilde{p}$	$\tilde{\pi}_i$
0.0	5.84969	35.8168	46.2748	1418.80
0.1	5.72382	36.0475	45.9287	1428.38
0.2	5.60803	36.2484	45.6274	1436.76
0.3	5.50107	36.4251	45.3623	1444.17
0.4	5.40187	36.5822	45.1268	1450.77
0.5	5.30953	36.7228	44.9159	1456.71
0.6	5.22328	36.8495	44.7257	1462.08
0.7	5.14246	36.9646	44.5531	1466.97
0.8	5.06651	37.0695	44.3957	1471.43
0.9	4.99494	37.1657	44.2514	1475.54
1.0	4.92734	37.2543	44.1185	1479.33

Source: own calculations

Table 6 provides the effect of changes in product differentiation on the behavior of firms in the case of an R&D cartel for the selected set of parameter values.

Table 6. R&D cartel – equilibrium for a = 100, c = 1, y = 3, β = 0.3, and $s \in [0,1]$

s	$\tilde{x}_i$	$\tilde{q}_i$	$\tilde{p}$	$\tilde{\pi}_i$
0.0	7.62840	45.8043	54.1957	2202.93
0.1	7.12752	43.5764	52.0660	2007.67
0.2	6.66963	41.5487	50.1416	1838.08
0.3	6.24900	39.6950	48.3965	1689.82
0.4	5.86082	37.9933	46.8094	1559.44
0.5	5.50107	36.4251	45.3623	1444.17
0.6	5.16631	34.9749	44.0402	1341.74
0.7	4.85364	33.6292	42.8304	1250.30
0.8	4.56049	32.3765	41.7222	1168.33
0.9	4.28471	31.2070	40.7067	1094.57
1.0	4.02442	30.1120	39.7760	1027.94

Source: own calculations

From table 6, it follows that an increasing differentiation of the final product (lower parameter s) generates an increase of R&D investment, a greater supply of the final product, as well as a higher price and profits. These relationships are not different from the case of R&D competition.

FULL INDUSTRY COOPERATION

Finally, we move on to the case when both companies created a cartel in the R&D stage as well as on the final product market. The demand functions and the cost functions are assumed to be the same as in the previous sections.

On the final product market, the companies decide about their production levels q_1 and q_2 to maximize the joint profit, given the size of R&D investments, x_1 and x_2:

$$\pi = (a - q_1 - sq_2)q_1 - \frac{{q_1}^2}{c+x_1+\beta x_2} - \frac{\gamma x_1^2}{2} + \\ + (a - q_2 - sq_1)q_2 - \frac{{q_2}^2}{c+x_2+\beta x_1} - \frac{\gamma x_2^2}{2}. \tag{11}$$

Since we consider the symmetric equilibria, we have $x_1 = x_2 = x$ and $q_1 = q_2 = q$, where q is the optimal supply level of each cartel member $\left(\frac{\partial \pi}{\partial q} = 0\right)$.

The calculations lead to:

$$q = \frac{a(c+(1+\beta)x)}{2(1+c+cs+(1+s)(1+\beta)x)}. \tag{12}$$

After substituting (12) into the inverse demand function given by (1), we obtain the symmetric equilibrium price of the final product:

$$p_1 = p_2 = p = \frac{a(2+c+cs+(1+s)(1+\beta)x)}{2(1+c+cs+(1+s)(1+\beta)x)}. \tag{13}$$

Next, we can describe the joint cartel profit as a function of R&D investments of the firms:

$$\pi = \frac{1}{2}\left(\frac{a^2(c+(1+\beta)x)}{1+c+cs+(1+s)(1+\beta)x} - 2\gamma x^2\right). \tag{14}$$

When the companies form a cartel in the R&D stage and in the final product market, the symmetric equilibrium takes place when the R&D investments of each of the firms (x) satisfy the following first order condition for profit maximization:

$$\frac{\partial \pi}{\partial x} = 0. \tag{15}$$

Denote the solution to the above equation as $\bar{x}$. After substituting $\bar{x}$ for x into (12), we obtain the production level of each firm; denote it by $\bar{q} = \bar{q}_1 = \bar{q}_2$.

The equilibrium price of the final product offered by each company is obtained by substituting $\bar{x}$ for x into (13); denote it by $\bar{p}$. By substituting $\bar{x}$ for x into (14), we obtain the equilibrium joint profit of the companies; denote it by $\bar{\pi}$. Thus, every company earns:

$$\bar{\pi}_1 = \bar{\pi}_2 = \frac{1}{2}\bar{\pi}. \tag{16}$$

Table 7 shows the results of a numerical analysis in the case of full industry cartelization for the selected parameter values.

Table 7. Full industry cartel – equilibrium for $a = 100$, $c = 1, y = 3, s = 0.5$, and $\beta \in [0,1]$

$\boldsymbol{\beta}$	$\bar{x}_i$	$\bar{q}_i$	$\bar{p}$	$\bar{\pi}_i$
0.0	6.11552	30.4778	54.2833	1467.79
0.1	5.98521	30.6399	54.0402	1478.26
0.2	5.86523	30.7805	53.8292	1487.42
0.3	5.75433	30.9040	53.6441	1495.53
0.4	5.65141	31.0134	53.4800	1502.76
0.5	5.55556	31.1111	53.3333	1509.26
0.6	5.46598	31.1991	53.2014	1515.14
0.7	5.38201	31.2788	53.0818	1520.49
0.8	5.30307	31.3514	52.9730	1525.38
0.9	5.22866	31.4178	52.8733	1529.88
1.0	5.15834	31.4789	52.7816	1534.03

Source: own calculations

Based on table 7, we consider the impact of R&D spillovers on the equilibrium conduct and performance of firms in the cartelized industry. An increasing level of R&D externalities induces a decline of R&D investments and of the final product price, but induces an increase of supply and profits of firms. We have observed this result in the case of R&D competition under patent protection as well as in the case of an R&D cartel.

Additional regularities can be observed by changing the degree of product differentiation measured by parameter s. Table 8 reports the calculation of the cartel equilibrium for various sizes of s, and for $\beta = 0.3$.

Table 8. Full industry cartel – equilibrium for $a = 100$, $c = 1, y = 3, \beta = 0.3$, and $s \in [0,1]$

$\boldsymbol{s}$	$\bar{x}_i$	$\bar{q}_i$	$\bar{p}$	$\bar{\pi}_i$
0.0	7.62840	45.8043	54.1957	2202.93
0.1	7.14330	41.7635	54.0601	2011.64
0.2	6.72546	38.3837	53.9396	1851.34
0.3	6.36105	35.5143	53.8314	1715.02
0.4	6.03991	33.0476	53.7334	1597.66
0.5	5.75433	30.9040	53.6441	1495.53
0.6	5.49839	29.0237	53.5621	1405.84
0.7	5.26744	27.3609	53.4865	1326.43
0.8	5.05780	25.8798	53.4164	1255.62
0.9	4.86647	24.5520	53.3512	1192.08
1.0	4.69102	23.3549	53.2902	1134.74

Source: own calculations

Table 8 shows that the R&D investments made by a cartel member ($\bar{x}$) are a declining function of the extent of product differentiation (parameter s). Similarly, a greater extent of R&D spillovers generates a lower supply of the final product, as well as lower price and profits. These relationships are similar to the case of R&D competition with or without patent protection (table 2 and table 4) as well as to case of R&D cartel (table 6).

DISCUSSION

We may use the equilibria obtained in the previous sections to compare the decisions of firms and their performance under the R&D competition with or without patent protection, and their behaviour in the case of different types of firms' cooperation.

First, we consider the decisions of companies regarding the investments in R&D when the final products offered by firms have a medium level of differentiation ($s = 0.5$). Surprisingly, the R&D investments under R&D competition without patent protection dominate the R&D investments under R&D competition with patent protection. The latter result applies to all values of R&D spillovers in the industry (cf., table 1 and table 3). Thus, the first prediction based on the literature review is rejected. It means that in a differentiated goods industry, the patent protection does not necessarily promote R&D investments and corporate innovation. The obtained result can be to some extent explained by the existence of tournament effect. Firms which compete for a patent are aware of the fact that only one firm can win the tournament and obtain a reward in the form of a patent. As a result, the individual R&D investments decrease if the reward is uncertain and R&D costs are likely to be sunk. The tournament effect limits the individual R&D investments under R&D competition with patent protection. In R&D competition without patents, the R&D investments directly translate into cost reductions and improve the competitive positions of firms. Under such market setup, the R&D investments do not constitute sunk costs.

When we look at the profits of firms under R&D competition with patents and without them, it turns out that the profits under R&D competition without patents dominate those under R&D competition with patents (cf., table 1 and table 3). It means that the enterprises, in the specified market environment, would prefer rivalry without patents to the competition with patent protection. The advantages (in terms of R&D investments and profits) of R&D competition without patents over R&D competition with patents hold for all values of the substitutability parameter (cf., table 2 and table 4).

Let us now compare the effectiveness of two selected innovation policy instruments, i.e., patents and R&D cooperation. Based on tables 3-6, we can say that R&D cooperation dominates (in terms of R&D investments and profits) R&D competition supported by patents. The latter claim supports the second prediction and is valid for all values of the substitutability parameter (cf., table 4 and table 6). It seems then that patents and R&D cooperation cannot be perceived as substitutes in the modern innovation policy. R&D cooperation dominates patent protection. As Penin (2005; 2012) observes, patents can be only a complementary tool in the public policy oriented at promoting innovation which should be based on cooperative R&D agreements. It seems then that R&D cooperation (a push policy instrument) exerts a powerful impact on private innovation. Interestingly enough, the effect of enhancing private innovation can be significantly larger in the presence of PPI (a pull policy instrument). As Stojčić et al. (2020) observe, PPI has a large effect on corporate innovation (both at the European and national level), and the highest additionality may be achieved when firms receive both financial support and innovation-oriented public procurement. According to Stojčić et al. (2020), policy-makers aiming to strengthen indigenous innovation capabilities should place stronger emphasis on PPI.

Our study does not measure the impact of the other push policy instruments, i.e., R&D tax credits, direct grants or subsidies, support of the university research and technology transfer from public labs. The impacts of the above supply-side instruments on private innovation needs to be investigated theoretically (with the use of mathematical models and numerical analysis), compared with the impacts of R&D cooperation or patents, and classified according to their relative strength or generated additionality effects. However, we set out to do it in another study. Interestingly enough, some empirical papers suggest that subsidies lead to additional R&D expenditures, but do not lead to additional innovation output (Hashi and Stojčić 2013). R&D tax credits, in turn, lead to additional innovation output (Czarnitzki et al. 2011). Finally, university technology transfer seems to stimulate break-through, high-tech innovation creation and commercialization (for a review, see Audretsch and Caiazza 2016).

Coming back to the obtained results, R&D cooperation does not dominate R&D competition without patents (cf., tables 1-2 and 5-6). For relatively low values of R&D spillovers in the industry (smaller than 0.5) and the value of substitutability parameter high enough, R&D competition without patents brings about larger R&D investments compared with R&D cooperation (cf., tables 1-2 and 5-6). For the relatively high values of R&D spillovers (higher than 0.5), R&D investments are larger under R&D cooperation than R&D competition without patents (cf., tables 1 and 5). The latter supports the second prediction. Thus, it can be claimed that R&D cartels speed up technological development for a sufficiently large size of R&D spillovers. Unfortunately, the prices offered by the R&D cartel members are significantly higher than the price levels expected under R&D competition.

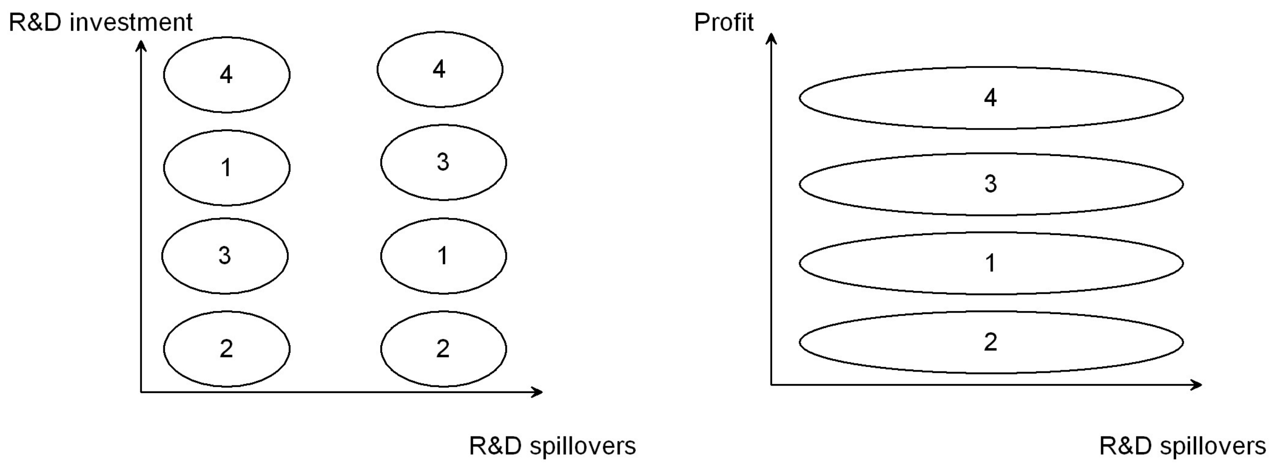
As regards profits (cf., tables 1-2 and 5-6), R&D cooperation brings about higher profits compared with R&D competition without patents for all values of R&D spillovers in the industry and for all values of the substitutability parameter.

The full industry cartel generates a higher R&D investment than the firms engaged in R&D competition under patent protection for any level of product differentiation (cf., tables 3 and 7). Moreover, an industry cartel spends more on R&D than an R&D cartel for all values of R&D spillovers in the industry and as long as $s > 0$ (cf., tables 5-8), and both types of cartels have identical spending on R&D when R&D spillovers are sufficiently low and products are fully heterogeneous ($s = 0$), cf., tables 5-8. Also, for the relatively high levels of product differentiation ($s \leq 0.4$), an industry cartel invests more than the R&D competitors without patent protection. However, when the level of product differentiation is not too high ($s \geq 0.5$), the industry cartel invests less than the non-cooperating firms without a possibility of patenting.

Further, it can be seen from tables 1 through 8 that the profit of a cartel member is always higher than the profit of a non-colluding firm. Interestingly, the profit of an industry cartel member dominates the profit of an R&D cartel member for all values of R&D spillovers in the industry and most of the values of the substitutability parameter (cf., tables 5-8). The results mentioned above support the third prediction. The numerical analysis shows that for any extent of product differentiation, it is always better for the firms to create a cartel in order to maximize profits rather than to engage in R&D competition.

Lastly, by comparing tables 2, 4, 6, and 8, it can be observed that for any level of product differentiation, the R&D investments are the smallest in the case of R&D competition with patent protection (cf., figure 2).

Figure 2. Graphical representation of the obtained results.



Source: own elaboration.
"1" – R&D competition without patent protection
"2" – R&D competition with patent protection
"3" – R&D cooperation
"4" – Full industry cooperation

CONCLUSIONS

In this paper, we considered the impact of patents and R&D cooperation on R&D investments made by firms operating in the oligopolistic market trading with differentiated products. Four types of firms' conduct in the industry were investigated: R&D competition without patents, R&D competition with patent protection, R&D cooperation (R&D cartel), and the entire industry cartel (full industry cooperation). The obtained results suggest that patents do not necessarily promote R&D investments due to the existence of so called tournament effects. R&D cooperation seems the effective instrument which stimulates R&D investments, but R&D cooperation provides sufficient incentives to create a full industry cartel. Such a cartel works to the detriment of consumers, since the market price under full industry cartel is higher compared with R&D competition without patents and R&D cooperation, and the market quantity is lower under full industry cartel compared with R&D competition without patents and R&D cooperation.

Our comparative analysis led us to the conclusion that for a relatively low level of R&D spillovers in the industry, the innovation policy-makers should promote R&D competition without patent protection among oligopolistic firms. For a relatively high level of R&D spillovers, R&D cooperation is the effective instrument which enhances corporate innovation, but the regulator should monitor the market for probable collusion. It is therefore, firms find it beneficial to extend an R&D cartel to the full industry cartel, since the latter brings about higher corporate profits.

As regards limitations of the present study, we should be aware of the fact that the above implications for policy-makers and managers hold for Cournot competition in the product market. One needs to test the results for Bertrand, Stackelberg, and price leadership models of competition. Also, the above conclusions apply to process innovations. One needs to test the above results in the future research concerning product innovations.

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