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R&D spillovers and cartelization of industries with differentiated products

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Abstract. The objective of this article is to investigate the impact of research and development (R&D) spillovers on cartelization of industries characterized by differentiated products. For simplicity, we focus on the duopoly market in which firms compete according to the Stackelberg leadership model. Numerical analysis shows that as long as products offered on the market are at least slightly differentiated, it is beneficial for firms to cooperate at the R&D stage, and form a cartel at the final product market. The threat of cartelizing industry is not present only under fully homogenous goods' competition. But, since the vast majority of product markets trade in differentiated goods, tightening cooperation in R&D generates a serious threat of industry cartelization. Thus, significant antitrust issues emerge.

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1. INTRODUCTION

The research goal of this paper is to investigate the impact of R&D spillovers on cartelization of industries characterized by differentiated products. The risk of industry cartelization is increased by the cooperation of enterprises in R&D (Martin, 2006; Miyagiwa, 2009; Belleflamme and Peitz, 2010). The latter conclusion has been however drawn without a closer look at the impact of the extent of product differentiation on the firms' incentives to cartelize industry. Therefore, there is a clear need to analyze the role of product differentiation on the markets threatened by collusion. Formal analysis of the product differentiation role in the process of market cartelization is present in the following paper, and such analysis, at least to some extent, closes the identified research gap.

The case of homogenous products has been already considered in Prokop and Karbowski (2013). These authors concluded that under relatively low level of knowledge spillovers in the industry, the enterprise that plays the role of the Stackelberg leader and thus will not be interested in creating a cartel in the industry. However, when the level of spillovers is relatively high, profits for the Stackelberg leader are lower than the profits gained by a firm in the cartelized industry, thus none of the firms would be interested in staying outside the cartel. Moreover, firms earn the largest profits when they fully internalize the knowledge spillovers and, at the same time, form an industry-wide cartel.

Product differentiation in the context of R&D competition and cooperation has been considered by Dixit (1979), followed by the work of Singh and Vives (1984), Harter (1993), Lin and Saggi (2002), Symeonidis (2003) and Cefis, Rosenkranz and Weitzel (2009), among others. In the light of those works, firms' investments in product R&D determine the degree of products' differentiation offered by the enterprises in the marketplace. When the goods offered at a market constitute close substitutes, product competition is intense. Gottinger (2013) suggests that the potential gains from the firms' R&D activities under intense product competition will be, to a high extent, dissipated to consumers. Tightening of cooperation between firms at the R&D stage may reverse this unfavourable (from the firm's viewpoint) result (Gottinger, 2013).

The remaining (and still unresolved) research issue is the role of significant product differentiation in industry cartelization (here goods are not close substitutes and product competition at the market is less fierce). What is then the relationship between the degree of final product differentiation and firms' incentives to cooperate in R&D and potentially create an industry cartel? The above question constitutes a research task that is addressed in this article.

The remainder of the paper is organized as follows. In the next section, the relevant innovation and R&D literature is reviewed. Next, the mathematical model of a non-cooperative duopoly is analyzed (in this framework, there is no cartel, either at the R&D stage, or at the final product market). We further consider the conduct and the performance of enterprises that formed a cartel at the final product market and coordinated their R&D expenditures, i.e., they have fully cartelized the industry. Due to the complexity of the analysed relationships, the equilibrium solutions are found numerically. Based on the comparison of the non-cooperative and cooperative scenarios, the discussion about the incentives for the firms to create a cartel is given in the subsequent section. Conclusions and references are closing the paper.

2. LITERATURE REVIEW

Williamson (2000, see also Joskow, 2008) identifies four interrelated levels of institutional analysis, i.e., embeddedness (or social foundations), institutional environment, governance and resource allocation. Embeddedness provides the basic foundations for a society's institutions, this level encompasses informal institutions, values and social norms and customs, among others (Joskow, 2008). Institutional environment encompasses what Williamson (2000) calls "the formal rules of the game" (e.g. constitution, judiciary system). Governance encompasses what Williamson (2000) calls "the play of the game" (organization of business). The basic structural features of the institutions through which decision-makers trade goods, services and production inputs are defined at governance level (Joskow, 2008). Resource allocation refers to the day-to-day operation of the economy given the institutions defined at the other three levels (prices, wages, costs and quantities bought and sold are determined at this level; Joskow, 2008).

Our analysis of the R&D competition and cooperation of firms is set at the governance (organization of R&D activities) and resource allocation (product prices, investment amounts, outputs) levels. R&D

competition and cooperation can be viewed from at least three different literature perspectives, i.e., the knowledge triangle perspective, innovation systems approach, and networked innovation approach.

The concept of knowledge triangle refers to the integration of innovation, research and (higher) education. These three areas are peculiar from the economic viewpoint due to the existence of externalities – both intrinsic and between the three areas indicated above (Soriano & Mulatero, 2010; Romer, 1990; Grossman & Helpman, 1991; Aghion & Howitt, 1992). Intrinsic externalities of the three areas indicated above are derived from the difference between private and social returns, i.e., the private returns to innovation, research and education are lower than the social ones. This usually leads to underinvestment in the three discussed areas, resulting in the market failure and call for public intervention (Hendrikse, 2003). Intrinsic externalities associated with the three analyzed areas justify the public policy focus (to correct the market failure). However, policy-makers have to also take into account the positive externalities arising between innovation, research and education and manage those interactions in a systemic and continuous way (Soriano & Mulatero, 2010).

Education produces skills that are indispensable inputs to research activities. Research activities conversely exert pressure on education what leads to education improvement. Education plays the key role in fostering innovation in the economy. In the light of endogenous growth theory (Romer, 1990; Grossman & Helpman, 1991; Aghion & Howitt, 1992) innovation and economic growth are positive functions of the educational level of labour force. The supply-side argument is that properly educated labour force is required to carry out innovative activities. Moreover, proper education is required for the labour force to fully benefit from new production technologies and organizational methods as well as easily adapt to innovative production and marketing solutions (Soriano & Mulatero, 2010). The demand-side argument is that education creates the effective demand for innovation – properly educated consumers are usually early adopters of new goods and services (Soriano & Mulatero, 2010).

Interactions between innovation, research and education, if inappropriately managed, may generate severe tensions (Maassen & Stensaker, 2011). A number of problems can be identified. For example, concentration of resources in research may actually weaken the strategic ability of universities (Geuna & Martin, 2003; Geiger, 2004; Maassen & Stensaker, 2011) in developing external links. Relevant studies show that the source of research funding plays here the important role, as industry funding is positively related to external collaboration and innovation networks (Gulbrandsen & Smeby, 2005). What is more, general incentives linked to research activities may actually be negatively related to innovation and technology transfer (Marksman et al., 2004; Maassen & Stensaker, 2011). Gilsing and others (2011) elaborate upon the frequent case of conflict of interests between firms and university researchers: business firms are focused on the appropriation of research results, whereas university researchers look for the dissemination of research results to gain a wide scientific reputation. In this context, it is of great importance to align university internal regulations as well as incentive and rewarding system not only to the university traditional role of scientific knowledge provider, but also to the novel, entrepreneurial mission (Etzkowitz, 1998).

According to Freeman (1991) and Okubo and Sjoberg (2000) R&D departments of business firms develop links to external sources of knowledge in order to facilitate successful innovation (Harryson et al., 2007). Research on interfirm collaboration shows that cooperative relationships emerge not as a substitute of internal corporate R&D, but as a complementary activity (Adams et al., 2001; Callon et al., 1992; Gibbons et al., 1994; Harryson et al., 2007). As a result, we observe the emergence of new, interactive models of knowledge generation (Etzkowitz, 2003b; Kruecken, 2003).

The interactions between different innovation actors lie at the heart of the innovation systems approach that aims at understanding the dynamics behind innovation, economic growth and competitiveness of nations (Freeman, 1987, 1991; Adams, 1990; Lundvall, 1992; Nelson, 1993; Mowery and Nelson, 1999; Baumol, 2002; Veugelers and Del Rey, 2014). An effective contribution to the capacity of an innovation system demands that higher education institutions not only create ideas that can be commercialized and transformed into new goods and services, but also that they are willing to become involved in the process of transferring knowledge towards commercial opportunities (Veugelers and Del Rey, 2014). This reasoning is supported by the Triple Helix literature of university-industry-government relations (Leydesdorff and Etzkowitz, 1998; Etzkowitz and Leydesdorff, 2000; Etzkowitz, 2003b). The organizing principle of the Triple Helix is that the university plays a greater role in society as an entrepreneur (in this concept entrepreneurial university takes over the central role of Schumpeterian entrepreneur in industrial dynamics, see Etzkowitz, 2003a; Schumpeter, 1934; Andersen, 2011). In the form of Triple Helix we observe specific and unique collaboration that presumes taking the role of the other (universities and firms assume some of the capabilities of the other: the entrepreneurial university takes a proactive stance in putting knowledge to commercial use and firms move closer to an academic model, involving in high levels of training and sharing of knowledge; Etzkowitz, 2003b).

On the basis of a review (Harryson et al., 2007) of several important publications in the field of R&D collaboration, the main advantages and benefits that companies expect in this context are:

• gaining access to and acquiring new knowledge in specialized fields (e.g. energy, health, raw materials, ICT, green technologies)
• creating a forum for networking by obtaining access to researchers, facilities and infrastructures,
• getting access to complementary skills and resources,
• enhanced R&D productivity by sharing R&D costs – sometimes also through access to government support,
• improved appropriability conditions and accelerated commercialization of R&D outputs.

The benefits of university partners who team up with companies are also manifold: improving the ability to conduct excellence-driven research and commercially exploit its results (Howells et al., 1998; Lee, 2000; Rogers et al., 1998); assuring proper protection, marketing and diffusion of the academic intellectual property and accelerating the rate of development of new products (Poyago-Theotoky et al., 2002; Rogers et al., 1998); gaining knowledge about practical problems for better alignment with industry and consumer needs (Lee, 2000; Lee and Win, 2004) as well as earning royalties – usually through IPR-licensing (for details, see Harryson et al., 2007).

R&D cooperative agreements of firms can be also perceived as networks consisting of diverse stakeholders coming from industry, academia, and policy. The networked innovation approach can be traced back to the sociological theory of strong and weak ties (Granovetter, 1973; Boase et al., 2003; Van Wijk, 2004). In the context of interorganizational cooperation qualities of weak ties determine network creativity and innovation (Granovetter, 1973; Harryson et al., 2007). According to Granovetter (1973) new ideas more often emanate through weak ties (from the margins of a specific network) rather than through strong ties (from the core of a specific network). It means that weak ties instead of strong ones are efficient for new knowledge acquisition and sharing (Harryson et al., 2007).

Networked innovation brings about a lot of advantages to network members. As we may read in the literature (Pittaway et al., 2004, p. 137), "principal benefits of networking [...] are risk sharing, obtaining access to new markets and technologies, speeding products to market, pooling complementary skills, safeguarding property rights when complete or contingent contracts are not possible".

Networked innovation paradigm stresses the role of science partners in the context of network formation. Industry-wide collaboration may galvanize the process of network formation and inject an impetus into the venture innovation project. From the networked innovation literature we can infer that interorganizational networks can generate radically new knowledge (through exploitation of numerous weak ties) at relatively high rate what usually leads to creation of break-through innovations (Harryson, 2006).

3. RESEARCH METHODS

We use standard microeconomic methods of analysis, i.e., mathematical modelling and optimization. As a complementary method, we turn to numerical analysis in order to show equilibrium solutions for the selected set of parameters. All computations have been run in Mathematica package. Mathematical modelling allows us to present the complex phenomenon of competition and cooperation of enterprises in the market with heterogeneous products in a consistent and functional way. Based on the derived mathematical formulas, we can elaborate upon the relationship between the extent of final product differentiation and the firms' incentives to cartelize the industry. The disadvantage of our approach is the fact that the developed model generates relatively complicated mathematical expressions, therefore the equilibrium solutions are found numerically.

Now, let us construct a mathematical model of firms' behavior on the heterogeneous product market.

First, consider an industry comprised of two firms, denoted 1 and 2. Firms manufacture q_1 and q_2 units of a heterogeneous product, respectively. The inverse market demand for the differentiated product is given as a linear price function:

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

where p_i denotes the market price, q_i is the volume produced by firm *i*, a is the demand intercept, and s is the substitutability parameter. Observe that both goods are perfect substitutes when $s = 1$, and each firm becomes a monopoly on the considered product market when $s = 0$.

Each of the companies is characterized by a linear function of the total manufacturing costs:

$$C_i(q_i, x_i, x_j) = (c - x_i - \beta x_j)\, q_i, \tag{2}$$

where $c \ (c < a)$ is a given parameter of an initial efficiency of firm *i*, x_i denotes the amount of R&D investments made by firm *i*, and x_j denotes the amount of R&D investments made by the competitor. Parameter $\beta \ (0 \le \beta \le 1)$ determines the size of R&D externalities, i.e., the benefits for a given company obtained as a result of research undertaken by the market rival (Geroski, 1995). Higher level of β means that the R&D investments made by one enterprise allow the competitor to reduce its manufacturing costs by a greater amount for free. The costs of the R&D investments have a form of quadratic function:

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

where $\gamma \ (\gamma > 0)$ is a given parameter. The entry barriers to the industry are viewed as too high for new enterprises to enter.

We further assume that in this industry one firm, say duopolist 1, plays the role of the Stackelberg leader, and the other enterprise, say firm 2, is the Stackelberg follower. Thus, firm 1 is the first to set the level of supply (q_1), and firm 2, given the production level set by the leader, decides upon its own output level (q_2).

The game proceeds in two stages. At the first stage, both enterprises simultaneously and independently decide upon their levels of R&D investments (x_i). These decisions affect the function of total manufacturing costs of each firm. At the second stage, the duopolists compete in the final product market according to the Stackelberg leadership model.

Consider the profit of the follower firm at the second stage of the game for a given amount of R&D investments, x_1 and x_2:

$$\pi_2 = (a - q_2 - sq_1)q_2 - (c - x_2 - \beta x_1)q_2 - \gamma \frac{x_2^2}{2}. \tag{4}$$

For a given output of the leader (q_1), the follower maximizes its own profit by setting the production level at:

$$q_2 = \frac{1}{2}(a - c - sq_1 + \beta x_1 + x_2). \tag{5}$$

Taking into account the follower's reaction given by (5), the leader maximizes its own profit, with a given size of research investments, x_1 and x_2:

$$\pi_1 = (a - q_1 - sq_2)q_1 - (c - x_1 - \beta x_2)q_1 - \gamma \frac{x_1^2}{2}. \tag{6}$$

The optimal production volume of the leader is given by:

$$q_1 = \frac{(a-c)(2-s)+(2-s\beta)x_1-(s-2\beta)x_2}{2(2-s^2)}. \tag{7}$$

By substituting (7) into (5), we obtain the optimal output of the follower:

$$q_2 = \frac{(a-c)\big(4-s(2+s)\big)+((4-s^2)\beta-2s)x_1+(4-s^2-2s\beta)x_2}{4(2-s^2)}. \tag{8}$$

The production levels q_1 and q_2 given by (7) and (8) constitute the Nash-Stackelberg equilibrium. After substituting (7) and (8) into (4) and (6), we obtain the equilibrium profits as functions of R&D investments, x_1 and x_2:

$$\pi_1(x_1, x_2), \tag{9a}$$

$$\pi_2(x_1, x_2). \tag{9b}$$

The equilibrium strategies at the first stage of the game are found as a solution to the following system of two equations with two unknowns, x_1 and x_2:

$$\frac{\partial \pi_1}{\partial x_1} = 0, \tag{10a}$$

$$\frac{\partial \pi_2}{\partial x_2} = 0. \tag{10b}$$

The above system has exactly one solution; denote it by x_1^* and x_2^*. By substituting x_1^* and x_2^* into (9a) and (9b), we obtain the equilibrium profits of the leader and the follower; denote them by π_1^* and π_2^*.

For the sake of further comparison, we now consider a scenario in which the enterprises have formed a cartel both at the R&D stage, and on the final product market. We assume that the demand function as well as the cost functions of the firms are the same as above.

At the second stage of the game, the firms choose their production levels, q_1 and q_2, to maximize their joint profit, given the amount of R&D investments, x_1 and x_2:

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

At the symmetric equilibrium, i.e. $x_1 = x_2 = x$, the optimal production level of each firm in the cartel is:

$$q_1 = q_2 = q = \frac{a-c+(1+\beta)x}{2(1+s)}. \quad (12)$$

Thus, after substituting (12) into the inverse demand function given by (1), we obtain the equilibrium price in the final product market as:

$$p = \frac{a+c-(1+\beta)x}{2}. \quad (13)$$

At the first stage of the game, when enterprises simultaneously choose x_1 and x_2, their joint profit becomes:

$$\tilde{\pi} = \frac{1}{2(1+s)}((a - c + (1 + \beta)x)^2 - 2(1 + s)\gamma x^2). \quad (14)$$

When the firms cooperate within a cartel, both in research and development and in the final product market, the symmetric equilibrium is reached when the research investments of each of the duopolists are:

$$\tilde{x} = \frac{(a-c)(1+\beta)}{2(1+s)\gamma-(1+\beta)^2}, \quad (15)$$

and the production level of each of the firms, after substituting (15) into (12), is:

$$\tilde{q} = \tilde{q}_1 = \tilde{q}_2 = \frac{(a-c)\gamma}{2(1+s)\gamma-(1+\beta)^2}. \quad (16)$$

The equilibrium price of the final product, after substituting (15) into (13), is:

$$p = \frac{(a+c)(1+s)\gamma-a(1+\beta)^2}{2(1+s)\gamma-(1+\beta)^2}. \quad (17)$$

From (23) follows that the profit of each of the firms under full cartelization of the industry becomes:

$$\tilde{\pi}_1 = \tilde{\pi}_2 = \frac{1}{2}\frac{(a-c)^2\gamma}{2(1+s)\gamma-(1+\beta)^2}. \quad (26)$$

4. ANALYSIS

We will now use a numerical analysis in order to show equilibrium outcomes. For the purpose of this paper, we will restrict our considerations to the case when three parameters of the model are: $a = 100$, $c = 10$, and $\gamma = 20$. The results of the calculations for $s = 0.5$ and various levels of parameter β are given in table 1.

Table 1

Stackelberg equilibrium for $a = 100, c = 10, \gamma = 20, s = 0.5$ and $\beta \in [0,1]$

β	x_1	x_2	q_1	q_2	p_1	p_2	π_1	π_2
0.0	1.97107	1.93457	39.4214	36.1119	42.5226	44.1774	1320.94	1266.65
0.1	1.92475	1.88564	39.4821	36.1687	42.4335	44.0903	1326.94	1272.61
0.2	1.87808	1.83696	39.5385	36.2217	42.3507	44.0091	1332.61	1278.27
0.3	1.83105	1.78764	39.5903	36.2709	42.2742	43.9339	1337.94	1283.62
0.4	1.7837	1.73799	39.6377	36.3163	42.2041	43.8648	1342.94	1288.67
0.5	1.73603	1.68804	39.6806	36.3579	42.1405	43.8018	1347.59	1293.40
0.6	1.68805	1.63780	39.7189	36.3956	42.0833	43.7450	1351.90	1297.82
0.7	1.63980	1.58728	39.7526	36.4294	42.0327	43.6943	1355.85	1301.91
0.8	1.59127	1.53650	39.7818	36.4593	41.9886	43.6498	1359.44	1305.67
0.9	1.54249	1.43422	39.8063	36.4853	41.9511	43.6116	1362.68	1309.11
1.0	1.49348	1.43422	39.8262	36.5073	41.9202	43.5796	1365.55	1312.21

Source: own calculations

Using table 1, let us consider the impact of parameter β, i.e., the extent of externalities in R&D, on the equilibrium behaviour of firms. When the external benefits for a given enterprise resulting from the research undertaken by the rival are relatively small (parameter β is low), the R&D investments of each firm are relatively high and they decline with the growing scale of spillovers. It is not a surprise that the follower invests in R&D a slightly smaller amount than the leader, because the latter derives greater product market benefits. The profits of each firm are increasing together with the larger extent of spillovers.

Additional observations can be made based on the changes of substitutability parameter s. Table 2 shows the Stackelberg equilibrium for various levels of s, and $\beta = 0.2$.

Table 2

Stackelberg equilibrium for $a = 100, c = 10, \gamma = 20, \beta = 0.2$ and $s \in [0,1]$

s	x_1	x_2	q_1	q_2	p_1	p_2	π_1	π_2
0.0	2.31956	2.31956	46.3918	46.3918	53.6082	53.6082	2098.39	2098.39
0.1	2.18883	2.18849	44.2187	44.1022	51.3711	51.4759	1897.61	1897.11
0.2	2.08119	2.07858	42.4732	42.0001	49.1268	49.5053	1724.58	1720.80
0.3	1.99418	1.98551	41.1171	40.0246	46.8755	47.6403	1574.77	1562.55
0.4	1.92651	1.90592	40.1356	38.1185	44.6170	45.8279	1444.88	1416.69
0.5	1.87808	1.83696	39.5385	36.2217	42.3507	44.0091	1332.61	1278.27
0.6	1.85024	1.77582	39.3669	34.2629	40.0754	42.1170	1236.56	1142.41
0.7	1.84643	1.71908	39.7082	32.1463	37.7894	40.0580	1156.34	1003.83
0.8	1.87353	1.66118	40.7290	29.7263	35.4899	37.6905	1092.92	856.06
0.9	1.94512	1.59053	42.7499	26.7523	33.1730	34.7728	1049.56	690.39
1.0	2.08969	1.47738	46.4375	22.7289	30.8336	30.8336	1034.55	494.78

Source: own calculations

From table 2, it follows that the relationship between the level of product differentiation and the size of research investments undertaken by the Stackelberg leader is non-monotonic. The highest level of product differentiation generates the largest size of R&D investments by both firms. When the product homogeneity measured by s increases from 0 to 0.7, the level of research investments made by the Stackelberg leader declines; a further increase of s (from 0.7 to 1.0) raises the R&D expenses of the leader. However, the follower reduces its research spendings together with a growing level of product homogeneity.

Based on table 2, it can be observed that an increased product differentiation raises the profits of each enterprise. Since the competition under the highest product differentiation is minimized, the firms enjoy the largest profits when $s = 0$; the lowest profits are achieved when products are homogenous, i.e., $s = 1$. It is worthwhile to mention that greater substitutability of products increases the gap between the profits of both companies with the leader being the more favourable situation. The maximal level of product differentiation results in no difference in profits between the leader and the follower in the Stackelberg competition.

Now, we move on to analyze the case of firms' cooperation within a cartel. The results of the calculations for various levels of parameter β have been presented in the table 3.

Table 3

Full cartelization equilibrium for $a = 100$, $c = 10$, $\gamma = 20$, $s = 0.5$ and $\beta \in [0,1]$

$\boldsymbol{\beta}$	$\tilde{\boldsymbol{x}}$	$\tilde{\boldsymbol{q}}_i$	$\boldsymbol{p}$	$\tilde{\boldsymbol{\pi}}_i$
0.0	1.52542	30.5085	54.2373	1372.88
0.1	1.68396	30.6175	54.0738	1377.79
0.2	1.84426	30.7377	53.8934	1383.20
0.3	2.00652	30,8695	53.6958	1389.13
0.4	2.17092	31.0131	53.4804	1395.59
0.5	2.33766	31.1688	53.2468	1402.60
0.6	2.50696	31.3370	52.9944	1410.17
0.7	2.67904	31.5181	52.7228	1418.32
0.8	2.85412	31.7125	52.4313	1427.06
0.9	3.03245	31.9206	52.1192	1436.42
1.0	3.21429	32.1429	51.7857	1446.43

Source: own calculations

Using table 3, let us consider the equilibrium behaviour of firms, for various levels of the parameter β. Under full cartelization of the industry, together with the increase in the scale of R&D externalities, there is also an increase in research investments aimed at the reduction of production costs. At the same time, we observe an increase in the supply of final products offered by each of the firms. That results in price reductions of the manufactured products when the amount of spillovers increases. Finally, the profits of each firm operating within a fully cartelized industry increase monotonically together with the growing extent of R&D externalities.

Further observations can be made based on the changes of product differentiation measured by parameter s. Table 4 shows the cartel equilibrium for various levels of s, and $\beta = 0.2$.

Table 4

Full cartelization equilibrium for $a = 100$, $c = 10$, $\gamma = 20$, $\beta = 0.2$ and $s \in [0,1]$

s	$\tilde{x}$	$\tilde{q}_i$	p	$\tilde{\pi}_i$
0.0	2.80083	46.6805	53.3195	2100.62
0.1	2.53759	42.2932	53.4774	1903.20
0.2	2.31959	38.6598	53.6082	1739.69
0.3	2.13608	35.6013	53.7184	1602.06
0.4	1.97947	32.9912	53.8123	1484.60
0.5	1.84426	30.7377	53.8934	1402.60
0.6	1.72634	28.7724	53.9642	1294.76
0.7	1.62260	27.0433	54.0264	1216.95
0.8	1.53061	25.5102	54.0816	1147.96
0.9	1.44850	24.1416	54.1309	1086.37
1.0	1.37475	22.9124	54.1752	1031.06

Source: own calculations

It follows from table 4 that the reduction in product differentiation (increasing *s*) leads to a reduction in R&D investments by cartel members.

5. DISCUSSION AND CONCLUSIONS

Comparing the equilibria under the Stackelberg competition and the performance of firms in the cartelized industry, we may draw the conclusions regarding the firms' incentives for R&D spendings and industry cartelization.

The numerical analysis shows that as long as products are differentiated $(s < 1)$, it is always better for both firms to create a cartel in order to maximize profits. Situation is different when products are homogenous, i.e., $s = 1$. In that case, the Stackelberg leader may prefer not to form a cartel. For example, when $s = 1$ and $\beta = 0.2$, the profit of the Stackelberg leader equals 1034.55 (table 2), but the profit of a firm in the cartel amounts to 1031.06 (table 4).

The case of homogenous products was already considered by Prokop and Karbowski (2013). These authors concluded that under relatively low level of spillovers, the enterprise that plays the role of the Stackelberg leader will not be interested in creating a cartel in the industry. However, when the level of R&D spillovers is high, the profits for the Stackelberg leader are lower than the profits gained by a firm in the cartelized industry, thus none of the firms would be interested in staying outside of the cartel. Moreover, the firms earn the largest profits when they fully internalize the R&D spillovers and, at the same time, they form an industry-wide cartel.

In this paper, we posed a question about the relationship between the degree of final product differentiation and firms' incentives to cooperate in R&D and eventually create an industry-wide cartel. Numerical analysis reveals that as long as products offered on the market are differentiated $(s < 1)$, it is always beneficial to both firms competing in the Stackelberg fashion to cooperate at the R&D stage and form a cartel in the final product market. The threat of cartelizing industry is not present only under homogenous goods' competition (i.e. $s = 1$). But, in the case of at least slight product differentiation, tightening the cooperation in R&D between firms may generate a serious threat of industry cartelization. Thus, apart from numerous benefits of R&D collaboration (see e.g. Kamien et al., 1992; Kaiser, 2002), it generates a serious risk of cartel formation, followed by all negative consequences to consumers and social welfare (Karbowski, 2015).

The obtained results extend the knowledge on the conditions conducive to the industry cartelization. It is commonly believed that cartels on the final product market are usually formed by symmetric firms operating in the homogenous good industry (e.g., cement, glass, carton industry, cf. Paha, 2010). The results obtained in the present paper question this common belief. Clearly, when one think about the cartel formation in various industries, it is not difficult to find examples of stable product market cartels created by asymmetric firms trading in heterogeneous products. The flagship examples are the Belgian or the Dutch beer cartels.

In April 2007, the European Commission fined Dutch brewers, Heineken, Grolsch and Bavaria, a total of 273.78 million euros for operating a cartel in the beer market in the Netherlands (Wils, 2007). The brewers coordinated the rebates granted to pubs and bars. Moreover, the brewers coordinated other commercial conditions offered to individual customers in the on-trade segment in the Netherlands, and engaged in customer allocation, both in the on-trade and the off-trade segment. The cartel was classified as a "very serious infringement", and the starting amount for the cartel member with the largest market share, Heineken, was set at 65 million euros. The starting amounts for the other parties were set at a proportionately lower levels based on their own position in the market. The cartel lasted more than 3 and a half years which resulted in an increase of 35% in total of the starting amount increased by the multiplier where applicable (Wils, 2007).

Clearly, further research on the cartels formed by the asymmetric firms operating in the heterogeneous good markets is necessary. In addition to the theoretical foundations of the analysis provided in this paper, it would be interesting to collect comprehensive and systemic data on the various industry cases to give the final qualification on the impact of R&D spillovers on the cartelization of industries. We leave it for another paper.

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