Abstract

The objective of this paper is to compare the impact of R&D competition (i) under patent protection and (ii) under no patent protection on enterprise innovation and performance with the impact of R&D cooperation in the form of R&D cartel on enterprise innovation and performance. For simplicity we focus on the case of duopoly. In particular, the impact of R&D competition and R&D cooperation on enterprise research investments, output, market price, company profits, consumer surplus and total social welfare was investigated. The analysis revealed that when competition is Cournot, for any level of research spillovers, the R&D investments under patent protection are smaller than in the case of no patent protection. When firms create a research cartel then, for any level of spillovers, the R&D investments will be higher than those under patent protection with Cournot competition. However, they will be higher than the R&D investments when Cournot competition takes place in the case of no patent protection only for relatively high levels of spillovers. When the level of spillovers is relatively low, the R&D investments in the case of Cournot competition with no patents are higher than in the case of research cartel formed by the duopolists.

1 Introduction

Kamien and colleagues (1992) distinguished four different patterns of R&D that may arise in the industry, i.e. (1) R&D competition, (2) R&D cartelization, (3) RJV (research joint-venture) competition and (4) RJV cartelization. R&D competition occurs when companies decide upon their R&D investments unilaterally, so as to maximize individual economic profits. R&D cartelization means that firms coordinate their R&D investments, but at the same time maintain competition in the production stage, so as to maximize the sum of their economic profits. RJV competition occurs in turn when companies act as in the R&D competition pattern, but the results of R&D activity are fully shared. Last but not least, RJV cartelization translates into forming an RJV in which companies share their knowledge, fully

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disclose their information and coordinate their R&D investments, so as to maximize the sum of the overall economic profits (for more details, please see Kamien et al., 1992).

According to Amir and colleagues (2011) R&D cartels can be perceived as an alternative to non-cooperative R&D. The incentives to form an R&D cartel are, according to the above-mentioned authors, particularly strong when knowledge spillover rates in the industry are either close to 0 per cent or close to 100 per cent. For mid-level values of technological spillovers the firms’ incentives to create an R&D cartel in the industry are very weak (and completely non-existent when the knowledge spillover rate in the industry is exactly 50 per cent; cf. Amir et al., 2011). When high-level technological spillovers are a case, forming an R&D cartel in the industry is believed to be an efficient way of internalizing the large knowledge externalities occurring in the market (see e.g. Bernstein and Nadiri, 1988; Kamien et al., 1992; Amir et al., 2011). Poyago-Theotoky (1999) in a non-tournament model and De Fraja (1993) in a tournament model (firms are engaged in a patent race) note that firms can in fact deliberately choose R&D disclosure rates and, to a high extent, determine the level of technological spillovers in the industry. Another thing remains however the firms’ ability to appropriate the disclosed knowledge, e.g. in the form of patents. But nowadays business firms can strategically use technological knowledge generated in the industry, e.g. via different forms of patent licensing or cross licensing (Haruna, 2004).

From the policy-maker’s viewpoint, the interesting question is however which form of enterprise R&D – (i) R&D cartel or (ii) R&D competition incentivized by a patent protection can bring about more innovation. The first form of R&D is oriented at seeking interfirm cooperation at the R&D stage, often leaving benefits from patent protection aside, whereas the second form is targeted at strictly competitive race for a patent that constitutes a reward in the form of a monopoly (see also Karbowski and Prokop, 2013). The above-mentioned “R&D cartels or patents” dilemma will be succinctly addressed in the following article.

The paper itself is organized as follows. In the next section, the case of a noncooperative duopoly is analyzed, i.e. there is no cartel neither at the R&D stage nor in the final product market. Separately, the analysis is run for (a) no patent protection and (b) patent protection case. In section 3, we consider the conduct and performance of companies that formed an R&D cartel and coordinated their R&D expenditures, but at the same time maintained competition in the production stage, so as to maximize the sum of their economic profits. Based on the comparison of the above two cases, the conclusions regarding the incentives for the companies to innovate are given in the last section.

2 Cournot Competition

Consider an industry composed of two firms, denoted 1 and 2. Firms manufacture \( q_1 \) and \( q_2 \) units of a homogeneous product, respectively. The market demand for the product is given as a linear price function:

\[
p = a - q_1 - q_2 ,
\]

where \( p \) denotes the market price, \( q_i \) is the volume produced by firm \( i \), while \( a \) is the demand intercept. Initially, the cost functions of each firm are given by a linear function:

\[
\frac{q_i}{c} ,
\]

where \( c \) is a given parameter of an initial efficiency of firm \( i \).

Since the entry barriers to the industry are assumed to be high, there is no issue of new entry to this industry.
The firms engage in a two-stage game. In the first stage, both companies simultaneously and independently decide about their levels of R&D investments, \( x_i \). The costs of investments are given as a quadratic function:

\[
\gamma \frac{x_i^2}{2},
\]

where \( \gamma (\gamma > 0) \) is a constant parameter.

In the second stage, the companies compete in the final product market according to the Cournot model, i.e. they set their production quantities simultaneously and independently. The outcome depends on whether there is patent protection or not.

First, let us consider the case of no patent protection. When firm \( i \) invests in R&D, its cost of manufacturing is given by the following function:

\[
C_i(q_i, x_i, x_j) = \frac{q_i}{c + x_i + \beta x_j},
\]

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. Parameter \( \beta \) (\( 0 \leq \beta \leq 1 \)) determines the size of R&D externalities, i.e. the benefits for a given company obtained as a result of research undertaken by the competitor (Geroski, 1995; Griliches, 1995). Higher level of \( \beta \) means that the R&D investments made by one company allow the competitor to reduce the manufacturing costs by a greater amount for free. The lack of patent protection means that there will be no possibility to exclude the rival from the benefits of R&D investment.

In the case of no patent protection, the profit of firm \( i \) in the second stage of the game for a given amount of R&D investments, \( x_1 \) and \( x_2 \) is given by:

\[
\pi_i = (a - q_i - q_j)q_i - \frac{q_i}{c + x_i + \beta x_j} - \gamma \frac{x_i^2}{2}.
\]

The first order conditions for profit maximization, \( \frac{\partial \pi_i}{\partial q_i} = 0 \), generate the optimal output level of each firm:

\[
q_i = \frac{1}{3} \left( a + \frac{1}{c + \beta x_1 + x_j} - \frac{2}{c + x_1 + x_j} \right).
\]

The outputs \( q_i \) (\( i = 1, 2 \)) 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, \( \pi_1 \) and \( \pi_2 \), as the function of research investments, \( x_1 \) and \( x_2 \).

In the first stage of the game, when firms simultaneously decide about their R&D spendings, the Nash equilibrium strategies are obtained as a solution to the following set of two equations with two unknowns, \( x_1 \) and \( x_2 \): \( \frac{\partial \pi_i}{\partial x_i} = 0 \) (\( i = 1, 2 \)). Under certain conditions satisfied by the parameters \( a, c, \gamma \) and \( \beta \), the above system has exactly one solution. Let’s denote it by \( x_1^* \) and \( x_2^* \). Substituting \( x_1^* \) and \( x_2^* \) for \( x_1 \) and \( x_2 \) in (5), we obtain the equilibrium profits of the of the firm; denote them by \( \pi_1^* \) and \( \pi_2^* \). Now, we can also calculate the equilibrium levels of output, \( q_1^* \) and \( q_2^* \). Since the equilibrium is symmetric, we have \( x_1^* = x_2^* \), \( q_1^* = q_2^* \), and \( \pi_1^* = \pi_2^* \).

For the analysis of social efficiency, we also consider consumer surplus and total welfare. The consumer surplus, \( CS \), is obtained as the area of a triangle under the demand
curve and above the market price. The total welfare, $TW$, is calculated as the sum of consumer surplus and the profits of both firms.

Due to a relatively vague algebraic form of the above solutions, we will use a simplified numerical analysis in order to show possibilities of certain outcomes. For the purpose of this paper, we will restrict our considerations to the case when three parameters of the model are: $a = 100$, $c = 1$, and $γ = 5$. The results of the calculations for various levels of parameter $β$ are given in Table 1.

Table 1 Cournot equilibrium under no patent protection for $a = 100$, $c = 1$, $γ = 5$, and $β ∈ [0,1]$

<table>
<thead>
<tr>
<th>$β$</th>
<th>$x_i^*$</th>
<th>$q_i^*$</th>
<th>$p$</th>
<th>$π_i^*$</th>
<th>$CS^*$</th>
<th>$TW^*$</th>
</tr>
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<tbody>
<tr>
<td>0.0</td>
<td>1.46132</td>
<td>33.1979</td>
<td>33.6042</td>
<td>1096.76</td>
<td>2204.20</td>
<td>4397.73</td>
</tr>
<tr>
<td>0.1</td>
<td>1.35544</td>
<td>33.1995</td>
<td>33.6010</td>
<td>1097.61</td>
<td>2204.42</td>
<td>4399.65</td>
</tr>
<tr>
<td>0.2</td>
<td>1.26125</td>
<td>33.2007</td>
<td>33.5986</td>
<td>1098.31</td>
<td>2204.58</td>
<td>4401.20</td>
</tr>
<tr>
<td>0.3</td>
<td>1.17638</td>
<td>33.2015</td>
<td>33.5969</td>
<td>1098.88</td>
<td>2204.69</td>
<td>4402.45</td>
</tr>
<tr>
<td>0.4</td>
<td>1.09904</td>
<td>33.2020</td>
<td>33.5959</td>
<td>1099.36</td>
<td>2204.75</td>
<td>4403.46</td>
</tr>
<tr>
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<td>1.02784</td>
<td>33.2022</td>
<td>33.5956</td>
<td>1099.74</td>
<td>2204.77</td>
<td>4404.36</td>
</tr>
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<td>33.5956</td>
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<td>33.6010</td>
<td>1100.67</td>
<td>2204.42</td>
<td>4405.75</td>
</tr>
<tr>
<td>1.0</td>
<td>0.73068</td>
<td>33.1979</td>
<td>33.6042</td>
<td>1100.77</td>
<td>2204.20</td>
<td>4405.73</td>
</tr>
</tbody>
</table>

Using table 1, let us consider the impact of parameter $β$, i.e. the size of R&D externalities, on the equilibrium conduct of firms. When the external benefits for a given company 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. The supply of the final product achieves its maximum for the parameter $β = 0.5$, which results in the lowest level of the market price, and the highest consumer surplus.

The profits of each firm are growing together with the greater extent of technological spillovers. Thus, when there is no patent protection both competing firms are interested in the largest extent of technological spillovers.

The total welfare is increasing with the level of technological spillover $β$ growing from 0 to 0.9, but when $β$ gets very close to 1.0, there is a slight decline in the total welfare.

Next, we consider the case of patent protection. When firm $i$ obtains the patent, it reduces its manufacturing cost according to (4). However, when firm $j$ ($j ≠ i$) obtains the patent, firm $i$ is not allowed to use the new technology and its manufacturing cost is characterized by the initial cost function given by (2). Assuming that both firms undertake R&D investments, each of them obtains the patent with probability half.

When patent protection is in place, the expected profit of firm $i$ at the second stage of the game is:

$$\pi_i^e = pq_i - 1/2γx_i^2 - \left( \frac{1}{c+x_i+βx_j} + \frac{1}{c} \right) \frac{q_i}{2}. \quad (7)$$

For given levels of R&D investments, the optimal production volume of firm $i$ in this case amounts to:
\[ q_i = \frac{1}{6} \left( 2a - \frac{1}{c} + \frac{1}{c+\beta x_i + x_j} - \frac{2}{c+x_i+\beta x_j} \right). \] (8)

After substituting (8) into (7), we obtain the equilibrium expected profit of firm \( i \) as the functions of R&D investments, \( x_1 \) and \( x_2 \):

\[ \pi^e_i (x_1, x_2), \] (9)

The Nash 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 \( x_2 \): \( \frac{\partial \pi^e_i}{\partial x_i} = 0 \) \((i = 1, 2)\). Under certain restrictions on the value of parameters \( a, c, \beta, \) and \( y \), the above system has exactly one solution; denote it by \( \hat{x}_1 \) and \( \hat{x}_2 \). Substituting \( \hat{x}_1 \) and \( \hat{x}_2 \) for \( x_1 \) and \( x_2 \) in (8), we obtain the equilibrium outputs of firms; denote them by \( \hat{q}_1 \) and \( \hat{q}_2 \). Now, we can also calculate the equilibrium expected profits of the firms, denote them by \( \hat{\pi}^e_1 \) and \( \hat{\pi}^e_2 \). Observe that the equilibrium is symmetric, thus \( \hat{x}_1 = \hat{x}_2 \), \( \hat{q}_1 = \hat{q}_2 \), and \( \hat{\pi}^e_1 = \hat{\pi}^e_2 \).

Table 2 shows the Cournot equilibrium under patent protection for various levels of parameter \( \beta \).

<table>
<thead>
<tr>
<th>( \beta )</th>
<th>( \hat{x}_i )</th>
<th>( \hat{q}_i )</th>
<th>( \hat{p} )</th>
<th>( \hat{\pi}^e_i )</th>
<th>( \hat{C}_S )</th>
<th>( \hat{T}_W )</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.04985</td>
<td>33.0854</td>
<td>33.8293</td>
<td>1091.89</td>
<td>2189.28</td>
<td>4373.05</td>
</tr>
<tr>
<td>0.1</td>
<td>0.97535</td>
<td>33.0863</td>
<td>33.8275</td>
<td>1092.32</td>
<td>2189.40</td>
<td>4374.05</td>
</tr>
<tr>
<td>0.2</td>
<td>0.90864</td>
<td>33.0869</td>
<td>33.8261</td>
<td>1092.68</td>
<td>2189.49</td>
<td>4374.85</td>
</tr>
<tr>
<td>0.3</td>
<td>0.84819</td>
<td>33.0874</td>
<td>33.8252</td>
<td>1092.98</td>
<td>2189.55</td>
<td>4375.51</td>
</tr>
<tr>
<td>0.4</td>
<td>0.79280</td>
<td>33.0877</td>
<td>33.8247</td>
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<td>4376.03</td>
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<td>4377.19</td>
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</tbody>
</table>

From table 2, it follows that under patent protection, the changes of the technological spillovers measured by \( \beta \) have similar impact on the Cournot equilibrium as in the case of no patent protection. However, comparing tables 1 and 2, it can be concluded that for every level of spillovers the research investments of firms are lower in the case of patent protection than in the case of no patents (\( \hat{x}_i < x^*_i \)). Thus, the tournament effect discussed by Chowdhury (2005) is confirmed, i.e. the existence of patent protection reduces the R&D spendings. Interestingly enough, the consumer surplus (\( \hat{C}_S \)), as well the total welfare (\( \hat{T}_W \)) are also lower in the case of patent protection. The only beneficiaries of patents are the firms, i.e. their profits are higher under patent protection. Also, when the firms fully compete, the total surplus is the highest under no patent protection.

Now, we move on to analyze the cooperation of firms in the R&D stage and competition in the final product market.

3 R&D Cartel
For the sake of comparison, we now consider a model in which the companies have formed a cartel at the R&D stage, but compete according to the Cournot model in the final product market. We assume that the demand function as well as the cost functions of the firms are the same as in the previous section. When firm create an R&D cartel, the existence of patent protection plays no role as long as the cooperation is not discontinued.\footnote{A cartel disruption may lead to patent disputes and lawsuits. We do not consider such possibilities in this paper.}

At the second stage of the game, the companies choose the production levels \( q_1 \) and \( q_2 \) simultaneously and independently to maximize their individual profits given by (5), for the fixed amounts of R&D investments, \( x_1 \) and \( x_2 \).

At the Cournot-Nash equilibrium, the optimal production level of each firm is calculated according to (6). After substituting (6) into (5) we obtain the profits of each firm, \( \pi_1 \) and \( \pi_2 \), as the function of research investments, \( x_1 \) and \( x_2 \).

In the first stage of the game, the companies choose the R&D investments, \( x_1 \) and \( x_2 \), to maximize their joint profit, \( \pi(x_1, x_2) = \pi_1 + \pi_2 \). When the firms cooperate within an R&D cartel, the equilibrium arises when the research investments of each of the companies are the solution to

\[
\frac{\partial \pi}{\partial \tilde{x}_i} = 0 \text{ for } i = 1, 2; \tag{10}
\]
denoted by \( \tilde{x}_i \). Since the equilibrium is symmetric, we have \( \tilde{x}_1 = \tilde{x}_2 \). The production level of each of the firms is obtained by substituting \( \tilde{x}_i \) for \( x_i \) in (6); denote the equilibrium quantity by \( \tilde{q}_i \); again \( \tilde{q}_1 = \tilde{q}_2 \). The equilibrium price of the final product offered by the companies is calculated by substituting \( \tilde{q}_i \) for \( q_1 \) and \( q_2 \) in (1); denote that price by \( \tilde{p} \).

Finally, the profit of each of the firms in the situation of R&D cooperation and Cournot competition in the final product market is obtained by substituting \( \tilde{x}_i \) for \( x_i \) and \( x_2 \), and by substituting \( \tilde{q}_i \) for \( q_1 \) and \( q_2 \) in (5); denote the equilibrium profit of firm \( i \) by \( \tilde{\pi}_i \); since the equilibrium is symmetric, we have \( \tilde{\pi}_1 = \tilde{\pi}_2 \).

For the sake of a comparison with the results obtained in the previous section, we will limit our numerical analysis to the case when the parameters are \( a = 100 \), \( c = 1 \), and \( \gamma = 5 \). The results of the calculations for various levels of parameter \( \beta \) have been presented in the table 3.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
\( \beta \) & \( \tilde{x}_i \) & \( \tilde{q}_i \) & \( \tilde{p} \) & \( \tilde{\pi}_i \) & \( CS \) & \( TW \) \\
\hline
0.0 & 1.05119 & 33.1708 & 33.6583 & 1097.54 & 2200.61 & 4395.69 \\
0.1 & 1.04896 & 33.1786 & 33.6429 & 1098.07 & 2201.64 & 4397.77 \\
0.2 & 1.04505 & 33.1855 & 33.6291 & 1098.54 & 2202.55 & 4399.64 \\
0.3 & 1.04000 & 33.1916 & 33.6168 & 1098.98 & 2203.37 & 4401.32 \\
0.4 & 1.03418 & 33.1972 & 33.6057 & 1099.38 & 2204.10 & 4402.86 \\
0.5 & 1.02784 & 33.2022 & 33.5956 & 1099.74 & 2204.77 & 4404.26 \\
0.6 & 1.02117 & 33.2068 & 33.5864 & 1100.08 & 2205.38 & 4405.55 \\
0.7 & 1.01429 & 33.2110 & 33.5780 & 1100.40 & 2205.94 & 4406.73 \\
0.8 & 1.00730 & 33.2148 & 33.5703 & 1100.69 & 2206.45 & 4407.83 \\
0.9 & 1.00027 & 33.2184 & 33.5632 & 1100.96 & 2206.93 & 4408.85 \\
1.0 & 0.99326 & 33.2217 & 33.5566 & 1101.22 & 2207.37 & 4409.80 \\
\hline
\end{tabular}
\caption{Equilibrium in the model of R&D cooperation and final product competition}
\end{table}

Using table 3, let us consider the equilibrium behaviour of firms, for various levels of the parameter \( \beta \), i.e. the size of technological spillovers. In the case of cooperation in the R&D stage, together with the increase in the scale of R&D externalities, there is also a decline
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 in an R&D cartel increase monotonically together with the growing extent of research externalities.

By comparing tables 2 and 3, we observe that when firms cooperate in the research activities, the level of R&D investments is higher than in the case of competitive outcome under patent protection \( \bar{x}_i > \tilde{x}_i \). Thus, similar to the conclusions of Che and Yang (2009), the existence of a research cartel generates higher incentives to innovate than in the case of full competition under patent protection.

The equilibrium levels of product manufacturing are higher in the case of R&D cartel rather than when the firms fully compete under patent protection. Since the consumer surplus is directly linked to the output levels, it is greater in the case of R&D cooperation rather than in the noncooperative situation under patent protection \( \tilde{C}S > \bar{C}S \). Also, profits earned by the companies are clearly higher when the R&D cartel is formed. Thus, the cooperation of firms in the research stage results in an increased social welfare in comparison to the noncooperative case under patent protection \( \tilde{T}W > \bar{T}W \).

By comparing tables 1 and 3, we observe that when firms cooperate in research and development, the level of R&D expenditures is higher than in the case of competitive outcome with no patents, but only for relatively high values of technological spillovers in the industry \( \beta \geq 0.5 \). This result is in line with the previous literature that treats R&D cooperation as an efficient way of internalizing the large knowledge externalities occurring in the market (see e.g. Bernstein and Nadiri, 1988; Kamien et al., 1992; Amir et al., 2011; Karbowski, 2016). The equilibrium levels of product manufacturing are higher in the case of R&D cartel rather than when the firms fully compete under no patent protection, but again for \( \beta \geq 0.5 \). For this range of technological spillover values, the equilibrium price is higher under competition with no patents than under R&D cartel, but company profits are significantly lower. What is also interesting, for a relatively high level of knowledge spillovers (threshold at 0.5), the values of consumer surplus and total welfare are higher under R&D cartel than under R&D competition with no patents.

4 Concluding Remarks

In this paper, we analyzed the impact of, first, R&D competition (i) with and (ii) without patents and, second, R&D cooperation in the form of R&D cartel on enterprise innovation and performance. In particular, the impact of R&D competition and R&D cooperation on enterprise research investments, output, market price, company profits, consumer surplus and total social welfare was investigated. The analysis revealed that when competition is Cournot, for any level of research spillovers, the R&D investments under patent protection are smaller than in the case of no patent protection. When firms create a research cartel then, for any level of spillovers, the R&D investments will be higher than those under patent protection with Cournot competition. However, they will be higher than the R&D investments when Cournot competition takes place in the case of no patent protection only for higher levels of spillovers \( \beta \geq 0.5 \). When the level of spillovers is relatively low \( \beta \leq 0.4 \), the R&D investments in the case of Cournot competition with no patents are higher than in the case of research cartel formed by the duopolists.

The above results are in line with the previous knowledge on the topic. Claude d’Aspremont and Alexis Jacquemin (1988) stated that when companies behave strategically, R&D cooperation leads to more R&D than R&D competition when knowledge spillovers are large but less R&D when technological spillovers are relatively small. This is also a case in
our study. What is more, our research shows that R&D cooperation between firms promotes enterprise innovation to a higher extent than R&D competition incentivized by patents. This may constitute one more argument against patents (see e.g. Boldrin and Levine, 2013; Karbowski and Prokop, 2013).

References


