GREED AND FEAR IN DOWNSTREAM R&D GAMES[1]

Adam Karbowski*
SGH Warsaw School of Economics

Abstract: *The aim of this paper is to investigate the firms' incentives to engage in process R&D under vertical industrial setting, when the raising rivals' cost effect is present. We show that R&D investment of the downstream duopoly firm raises the rival's marginal costs of production. The downstream R&D behavior can give rise to the symmetric investment games, i.e., the prisoner's dilemma, the deadlock game and the harmony game, between downstream competitors. If the costs of the R&D investments made by the downstream firms are large enough, the downstream firms can participate in the harmony game, which results in the investment hold-up or the creation of the R&D-avoiding cartel. For more R&D-efficient downstream firms, the downstream investment game can end up in the prisoner's dilemma or the deadlock game. In the prisoner's dilemma, both downstream firms invest in R&D, but such a behavior is not Pareto optimal. In the prisoner's dilemma, greed and fear make firms invest in R&D. In the deadlock game, both downstream firms invest in R&D, and such a behavior is Pareto optimal. The R&D investments are not induced by any social tension (greed or fear).*

Key words: *R&D, investments, prisoner's dilemma, deadlock game, harmony game.*

CHCIWOŚĆ I STRACH W GRACH Z INWESTYCJAMI BADAWCZO-ROZWOJOWYMI

Streszczenie: *Celem artykułu jest zbadanie bodźców przedsiębiorstw do angażowania się w procesowe badania i rozwój w ramach przemysłowej struktury pionowej (dostawca-odbiorca), gdy obecny jest efekt podniesienia kosztu rywali. W pracy pokazano, że inwestycje badawczo-rozwojowe odbiorcy działającego na rynku duopolu podnoszą koszty krańcowe produkcji konkurenta. Zachowanie odbiorców w zakresie inwestycji badawczo-rozwojowych prowadzi do powstania*

[1] This research was supported by National Science Centre, Poland (grant number UMO-2016/21/B/HS4/03016)
* Adam Karbowski, Department of Business Economics, Collegium of World Economy, SGH Warsaw School of Economics, Al. Niepodległości 162, 02-554 Warsaw, Poland e-mail: adam.karbowski@sgh.waw.pl

 DOI: 10.7206/DEC.1733-0092.131

symetrycznych gier, tj. dylematu więźnia, zakleszczenia i harmonii, pomiędzy konkurującymi odbiorcami. Jeśli koszty inwestycji badawczo-rozwojowych są wystarczająco wysokie, odbiorcy uczestniczą w grze „harmonia", która skutkuje powstrzymaniem się od inwestycji lub powstaniem kartelu unikającego badań i rozwoju. Dla przedsiębiorstw efektywniejszych w zakresie badań i rozwoju interakcja pomiędzy odbiorcami może przyjąć postać dylematu więźnia lub zakleszczenia. W dylemacie więźnia obaj odbiorcy inwestują w badania i rozwój, ale takie zachowanie nie jest Pareto optymalne. W dylemacie więźnia dwa napięcia społecznego: chciwość oraz strach sprawiają, że przedsiębiorstwa inwestują w badania i rozwój. W przypadku zakleszczenia obaj odbiorcy inwestują w badania i rozwój, a takie zachowanie jest Pareto optymalne. Jednakże inwestycje badawczo-rozwojowe nie są motywowane w tym przypadku napięciem społecznym (chciwością lub strachem).

Słowa kluczowe: *badania i rozwój, inwestycje, dylemat więźnia, zakleszczenie, harmonia***.**

1. Introduction

Most industrial organization papers on R&D focus on horizontal relations between firms (Geroski, 1992; Harabi, 2002; Ge et al., 2014; Belderbos et al., 2018). The understanding of R&D in vertically related industries is limited (Inkmann, 2000; Ge et al., 2014). The works on R&D in vertical setting (Atallah, 2002; Ishii, 2004; Manasakis et al., 2014; Xu et al., 2015; Dai et al., 2017; Jullien et al., 2018) usually compare firms' R&D investments under different R&D regimes, i.e., non-cooperative R&D, R&D cartels, research joint ventures (RJVs), and RJV cartels. Under non-cooperative R&D, firms make R&D decisions unilaterally, focusing on their individual profits. Members of the R&D cartel coordinate their R&D investments, but remain competitors in the product market. Firms in an RJV take their R&D decisions and decisions on the final products unilaterally, yet they share the know-how. An RJV cartel consists in the know-how sharing with the concurrent coordination of R&D investments (the competition in the product market is retained).

The corporate R&D decisions in vertical structures are particular due to the possible existence of both positive and negative externalities. In horizontal R&D, the investments made by one firm exert a positive impact on the manufacturing costs of the rival firms (R&D spillovers, Kamien et al., 1992; Kamien and Zang, 2000;

 DOI: 10.7206/DEC.1733-0092.131

Karbowski, 2019). In the vertical case, the R&D investments made by a downstream firm can exert a positive impact on the manufacturing costs of the rivals via horizontal R&D spillovers, but also increase the demand for an input, allowing the upstream supplier to raise the input price (Banerjee and Lin, 2003). The increase in input price constitutes a negative externality for the downstream competitors, since it exerts a negative impact on the production costs of the rival downstream firms. This raising rivals' costs effect can be used strategically by a downstream competitor to gain an advantage over the downstream rivals.

The idea of obtaining a competitive advantage over rivals via cost raising is not new in the industrial organization literature (Salop and Scheffman, 1983; 1987; Salinger, 1988; Ordover et al., 1990; Banerjee and Lin, 2003; Dertwinkel-Kalt et al., 2015; Bernes et al., 2019). There are different cost-raising strategies that can be used to disadvantage market rivals. To those strategies belong: denying rivals' access to the market, inducing input suppliers to discriminate against competitors, lobbying about regulations that disadvantage competitors, commencing R&D or advertising wars, and adopting incompatible technologies (Salop and Scheffman, 1987). All those strategies are predatory in nature, therefore they are often called non-price predatory strategies (Salop and Scheffman, 1987).

As Banerjee and Lin (2003) noticed, the industrial organization models of vertical relations and foreclosure (see also, Salinger, 1988; Ordover et al., 1990; Choi and Yi, 2000; Hortacsu and Syverson, 2007; Jullien et al., 2018) show that downstream firms can effectively raise the input price for the rival downstream enterprises via strategic merger or takeover of the upstream supplier. The same effect (the increase in input price for the downstream rivals) can be also achieved without vertical integration, i.e., via process R&D investments made by the downstream enterprises. In such a case, the downstream firms face the peculiar incentives, on the one hand, the firms can reduce their own costs through R&D investments leading to process innovations, but, on the other hand, they can also increase the costs of the rival firms through R&D investments leading to the input price changes. The presence of such intertwined incentives entangles the downstream firms in a strategic interaction with respect to R&D investment decisions. We hypothesize that the above strategic interaction can give rise to social tensions (greed and fear) between downstream competitors who are thereby caught in the social dilemma over their R&D decisions.

The purpose of this paper is to investigate the firms' incentives to engage in process R&D under vertical industrial setting, when the raising rivals' cost effect is present. As regards paper novelty, unlike the previous literature on the topic, we take account of different R&D-efficiencies of firms and the impact of those efficiencies on the strategic R&D interactions which can occur between downstream competitors.

We contribute to the growing body of literature on R&D investment games (see, Conti and Marini, 2019, for the latest review). Some authors have already identified social dilemmas in the R&D strategic interactions between firms. Lambertini and Rossini (1998), Amir et al. (2011a), Amir et al. (2011b) and Burr et al. (2013) identified a prisoner's dilemma in firms' R&D decisions under horizontal industrial setting. The prisoner's dilemma explains why firms refrain from the R&D investments under horizontal industrial setting. Amir et al. (2011b) suggest that the prisoner's dilemma underlies the creation of the R&D-avoiding cartel (its members are better off when they refrain from R&D investments compared with investing in R&D). We, in turn, identify the prisoner's dilemma, the deadlock game and the harmony game in firms' initial R&D investments, but in a vertical industrial setting. In contrast to horizontal models mentioned above, prisoner's dilemma under vertical industrial setting makes firms invest in R&D. Interestingly enough, firms under the downstream prisoner's dilemma invest in R&D due to the existence of two social tensions, i.e., greed and fear. The deadlock game also makes firms invest in R&D, but the R&D investments are not induced by the social tensions. Lastly, the downstream harmony game makes firms refrain from R&D investments, and gives rise to the creation of the downstream R&D-avoiding cartel.

The remainder of this paper is organized as follows. The next section presents a simple model of vertical relations between firms operating in a supply chain. Further, we concentrate on the initial R&D investment games between downstream enterprises, and identify three symmetric games (prisoner's dilemma, deadlock game, harmony game) of the downstream competition. The concluding remarks close the paper.

2. The model of the vertically related industry

Consider the vertically related industry as in Banerjee and Lin (2003), but composed of one upstream firm, U, and two downstream firms, denoted 1 and 2. The upstream monopolist supplies an input to the downstream duopolists at the price w. Without loss of generality, we normalize the costs of the supplier to zero. The downstream firms produce q_1 and q_2 units of a homogeneous good, respectively. The production of each unit of the final good requires one unit of the input purchased from the supplier. The marginal cost of producing the final good for the downstream firm is $c + w$, where c denotes the cost of input transformation into the final good.

 DOI: 10.7206/DEC.1733-0092.131

The market demand for the final good is given as a standard linear price (p) function $p = p(q_1, q_2) = a - q_1 - q_2$, where $a > 0$ is a given parameter which indicates the market size. The downstream competition is a quantity competition of Cournot type.

Now, both downstream firms can invest in R&D and introduce process innovations resulting in the decrease of the marginal costs of manufacturing. The values of autonomous cost reduction due to R&D investments made by firms are x_i, $i = 1,2$. When we take account of firms' R&D investments, the marginal cost of producing the final good for the downstream firm is $c - x_i + w$. The costs of the R&D investments have a form of quadratic function (d'Aspremont and Jacquemin, 1988), reflecting the diminishing returns to R&D investment (Dasgupta, 1986), γx_i^2, where γ is an R&D efficiency parameter. Since the second order condition for the R&D maximization problem solved further within our model is $\gamma > \frac{49}{144}$, we assume that $\gamma > \frac{49}{144}$. For lower values of γ, the R&D cost function is not convex enough to guarantee the validity of the second order conditions for R&D maximization problems, i.e., finding such cost reductions which maximize firms' profits. The entry barriers to the industry are sufficiently high for the new firms to enter (Kamien et al., 1992). This assumption guarantees that the downstream market structure will not change to the monopolistic competition, for which the long run equilibrium profits earned by firms would be equal zero.

The game proceeds as follows. First, both Cournot firms simultaneously and independently decide upon their levels of R&D investments. These decisions affect the values of the manufacturing costs (process R&D investments reduce firms' manufacturing costs). Next, the supplier sets the price of the input, and the downstream firms compete in the product market according to the Cournot model (simultaneous and independent decisions on the production levels).

This sequential game can be solved by the backward induction. Given the firms' autonomous cost reductions due to R&D investments and the input price, the equilibrium outputs for the downstream firms are as follows:

$$q_1 = \frac{a - c - w + 3x_1 - (x_1 + x_2)}{3}$$
$$q_2 = \frac{a - c - w + 3x_2 - (x_2 + x_1)}{3}.$$

The upstream monopolist sets the optimal input price equal $w = \frac{a - c + \Sigma x_i / 2}{2}$. Now we can plug the optimal input price into the equilibrium outputs of the downstream competitors, and we obtain the following:

$$q_1 = \frac{1}{6}\{(a-c)+2[3x_1-(x_1+x_2)]-\Sigma x_i/2]\}$$
$$q_2 = \frac{1}{6}\{(a-c)+2[3x_2-(x_2+x_1)]-\Sigma x_i/2]\}.$$

The profits of the downstream firms can be expressed as follows:

$$\pi_1 = [a-q_1-q_2-(c-x_1+w)]q_1-\gamma x_1^2$$
$$\pi_2 = [a-q_2-q_1-(c-x_2+w)]q_2-\gamma x_2^2.$$

The symmetric profit-maximizing level of autonomous cost reduction due to R&D investment for each of the downstream duopolists is equal $x^s = \dfrac{a-c}{\gamma\frac{72}{7}-1}$.

Finally, let us compute the marginal cost of producing the final good for the downstream firm, and observe the changes of this cost due to process R&D investments. The marginal cost of production for the downstream firm is equal $c-x_i+w = \dfrac{a+c+\Sigma x_j/2-2x_i}{2}$ for $i,j=1,2$ and $i \neq j$. Observe that the derivatives of the marginal cost for a given firm with respect to the firms' autonomous cost reductions are constant and equal, respectively:

$$\frac{\partial(c-x_i+w)}{\partial x_i} = -\frac{3}{4}$$
$$\frac{\partial(c-x_i+w)}{\partial x_j} = \frac{1}{4}.$$

Based on the above formulas, we can identify the raising rivals' cost effect in our simple game and summarize this effect in the following proposition.

Proposition 1 (the proof follows from direct computation). A unit increase in the downstream firm's autonomous cost reduction decreases the firm's marginal cost by $\frac{3}{4}$ and rises the marginal cost of the rival duopolist by $\frac{1}{4}$.

3. Greed and fear in R&D investment games

Based on the analysis present in the previous section, let us discuss the downstream firms' incentives to engage in process R&D and reduce marginal costs of production. Following proposition 1, we study the strategic effects of a unit initial

 DOI: 10.7206/DEC.1733-0092.131

R&D investment ($x_i = 1$) made by the downstream firms. Downstream firms can take decision to either invest a unit in process R&D (strategy RD) or not to invest (strategy NRD). If both Cournot competitors decide to invest in process R&D, the payoff is $\frac{1}{2} - \gamma$ for both firms. The investing firm reduces its marginal cost of production by $\frac{3}{4}$ and, at the same time, increases the marginal cost of production for the rival firm by $\frac{1}{4}$. The cost of a unit initial R&D investment is γ. If both firms invest in R&D, the firm benefits the overall decline in its marginal cost of production by $\frac{1}{2}$. If only one Cournot competitor invests in R&D, she/he benefits the reduction of the marginal cost of production by $\frac{3}{4}$. The cost of the acquisition of the above benefit for the investing firm is equal γ. The firm refraining from the process R&D investment faces the increase of the marginal cost of production by $\frac{1}{4}$. This increase is due to the negative externality (raising rivals' cost effect) resulting from the decision made by the downstream rival. Lastly, if both Cournot competitors refrain from initial R&D investments, the marginal costs of production remain intact. Both the benefits and costs of process innovation are equal zero.

The initial R&D investment game described above can be easily presented in a strategic form (see table 1 below). The row and the column players represent the downstream Cournot competitors. For some restrictions imposed on the payoffs (we discuss them further in this section), the considered R&D investment game constitutes prominent examples of symmetric games, i.e., the prisoner's dilemma, the deadlock game, and the harmony game (Farahani and Sheikhmohammady, 2014; Płatkowski, 2017; Rusch, 2019).

Table 1
The unit initial R&D investment game in a strategic form

	NRD	**RD**
NRD	0; 0	$-\frac{1}{4}; \frac{3}{4}-\gamma$
RD	$\frac{3}{4}-\gamma; -\frac{1}{4}$	$\frac{1}{2}-\gamma; \frac{1}{2}-\gamma$

Source: own elaboration.

Let us now transform the above payoff matrix into the standard symmetric social game form (Curtis Eaton, 2004; Farahani and Sheikhmohammady, 2014; Płatkowski, 2017). Let NRD equal C (cooperation or collusion) and let RD equal D (defection). Since the investment game is symmetric, we can simplify its presentation and use the payoffs for only one player (here, the row player). Let 0 equal R (reward), $\frac{3}{4}-\gamma$ equal T (temptation), $\frac{1}{2}-\gamma$ equal P (punishment) and $-\frac{1}{4}$ equal S (sucker). The simplified payoff matrix reads as follows (see table 2).

Table 2
The unit initial R&D investment game as a symmetric social game

	C	**D**
C	R	S
D	T	P

Source: own elaboration.

Note that the above game constitutes a social dilemma for $\frac{1}{2}<\gamma<\frac{3}{4}$. If the last condition holds, the game satisfies all axioms of the two-player social dilemma (Płatkowski, 2017, for a multiplayer social dilemma). These axioms are as follows:

Axiom 1. 2 C-players are better off than 2 D-players.

Axiom 2. The payoffs are non-decreasing functions of the number of cooperators.

Axiom 3. Strategy C does not dominate strategy D.

Moreover, it is worth observing that for $\frac{1}{2}<\gamma<\frac{3}{4}$ the above game constitutes a particular type of social dilemma, i.e., the prisoner's dilemma. The prisoner's dilemma is defined by the following inequality $T>R>P>S$. One may check that for $\frac{1}{2}<\gamma<\frac{3}{4}$ the last inequality holds.

Observe further that the prisoner's dilemma between downstream Cournot competitors occurs due to the existence of specific social tensions, i.e., fear and greed.

Fear in the two-player social dilemma exists if for the cooperating player $P_d(0)>P_c(1)$, where $P_c(1)$ is the payoff for a player who plays strategy C if only she/he uses this strategy, and $P_d(0)$ is the payoff for a player who defects (chooses strategy D) if no-one cooperates. We say that fear is present in the game if defection is a safer

DOI: 10.7206/DEC.1733-0092.131

choice. For $\frac{1}{2} < \gamma < \frac{3}{4}$, the condition which defines fear holds in the R&D investment game. Greed, in turn, exists in the two-player social dilemma if for the cooperating player $P_c(2) < P_d(1)$, where $P_c(2)$ is the payoff for a player who plays strategy C if the opponent cooperates, and $P_d(1)$ is the payoff for a player who defects if the opponent cooperates. Again, for $\frac{1}{2} < \gamma < \frac{3}{4}$ in the R&D investment game, the condition which defines greed holds.

Due to the presence of both fear and greed, rational and self-interested (Coase, 1976) players use strategy D (the pair DD or, alternatively, RDRD constitutes Nash equilibrium in the analyzed prisoner's dilemma game). For the considered investment game it means that both downstream competitors invest in process R&D. Paradoxically, both firms would be however better off if they both played strategy C, i.e., they both refrained from the R&D investments. For the firms' given R&D efficiency, $\frac{1}{2} < \gamma < \frac{3}{4}$, the costs of R&D outweigh the process innovation benefits. Fear and greed make firms use R&D strategies (DD) which are not Pareto optimal. Interestingly enough, the prisoner's dilemma in firms' R&D investments gives rise to a potential tension between producer payoff and consumer payoff. Firms would be better off if they coordinated their R&D decisions and created the R&D-avoiding cartel (Amir et al., 2011b). The R&D-avoiding cartel would refrain from the process R&D investments, bringing firms higher payoffs. On the other hand, the R&D-avoiding cartel would not benefit the consumers, who, in general, value innovation, since the latter usually enhances the consumer welfare (Aghion et al., 2005; Marshall and Parra, 2019).

Let us now analyze the incentives to engage in process R&D for more and less R&D-efficient firms compared with the already considered case, i.e., $\frac{1}{2} < \gamma < \frac{3}{4}$. For more R&D-efficient firms, $\gamma < \frac{1}{2}$. From the second order condition of a downstream firm's profit maximization with respect to the R&D cost reduction follows $\gamma > \frac{49}{144}$. We thus consider the range $\frac{49}{144} < \gamma < \frac{1}{2}$ for the most R&D-efficient downstream firms. If $\frac{49}{144} < \gamma < \frac{1}{2}$, the unit initial R&D investment game constitutes a deadlock game (Brams, 1992; Hansel et al., 2018). The deadlock game is defined by the following inequality $T > P > R > S$. One may check that the above condition holds if $\frac{49}{144} < \gamma < \frac{1}{2}$. The Nash equilibrium of the deadlock game is DD, or RDRD when we refer to the R&D decisions of Cournot duopolists. The rational self-interest tells now both downstream competitors to invest in process R&D. Observe that in the deadlock game, unlike the prisoner's dilemma, the Nash equilibrium is also the Pareto choice. We also do not have here a space for a conflict between producer and consumer interest. Firms are interested in investing in R&D, and the R&D investments are valued by consumers. It is also worth noting that in the deadlock case there are no social tensions (fear or greed) which affect firms' choices. The most-R&D efficient downstream firms do not enter a social dilemma in their initial R&D investment decisions.

The class of the least R&D-efficient downstream firms ($\gamma > \frac{3}{4}$) also do not enter a social dilemma in their initial R&D investments. For $\gamma > \frac{3}{4}$, the considered R&D game constitutes a harmony game (DeCanio and Fremstad, 2013; Wakeley and Nowak, 2019). The harmony game is defined by the following inequalities $R > T$ and $S > P$. One may observe that the above conditions hold if $\gamma > \frac{3}{4}$. The Nash equilibrium of the harmony game is CC, or NRDNRD when we refer to the R&D decisions of downstream competitors. The rational self-interest tells now both Cournot firms to refrain from the R&D investments and form an R&D-avoiding cartel (Amir et al., 2011b). Unlike the prisoner's dilemma, the Nash equilibrium of the harmony game is also the Pareto choice. Unlike the R&D deadlock game, for the harmony case, we encounter the actual tension between producer and consumer interest. Downstream competitors maximize their payoffs if they refrain from R&D activities or hold up investments. Such a scenario disadvantage consumers compared with the firms' investing in process R&D. Finally, it is worth noting that for a harmony case, there are no social tensions (fear or greed) involved in firms' R&D choices.

To recapitulate the above discussion, we present the following table with the ranges of the parameter and the corresponding games.

For $\gamma < \frac{49}{144}$, the R&D cost function is not convex enough to guarantee the validity of the second order conditions for R&D maximization problems, i.e., finding such cost reductions which maximize firms' profits.

For $\gamma = \frac{1}{2}$, the R&D investment game is neither the deadlock nor the prisoner's dilemma game, and exhibits one Nash equilibrium in pure strategies – mutual investment in R&D, which is also the Pareto choice.

 DOI: 10.7206/DEC.1733-0092.131

Table 3
The ranges of the R&D efficiency parameter and the corresponding games

Condition	Type of game	Remarks
$\frac{49}{144} < \gamma < \frac{1}{2}$	The deadlock game	Nash equilibrium is the mutual investment in R&D; Nash equilibrium is the Pareto choice
$\frac{1}{2} < \gamma < \frac{3}{4}$	The prisoner's dilemma game	Nash equilibrium is the mutual investment in R&D; Nash equilibrium is not the Pareto choice
$\gamma > \frac{3}{4}$	The harmony game	Nash equilibrium is the mutual restraint on the R&D investments; Nash equilibrium is the Pareto choice

Source: own elaboration.

Finally, for $\gamma = \frac{3}{4}$, the R&D investment game is neither the prisoner's dilemma nor the harmony game, and exhibits four Nash equilibria in pure strategies – mutual investment in R&D, mutual restraint on the R&D investments, and two other equilibria in which one firm invests in R&D and the second firm refrains from R&D investment.

4. Conclusions

As Amir and colleagues (2011b) notice, firms might conduct process R&D with the sole intent of keeping up with their rivals. For process innovations, in order to keep up with the innovative rivals, a firm has to invest in process R&D leading to the reduction of marginal costs of production. Obviously, the participation in the process innovation "arms race" is not costless. The firms have thus to assess the benefits from the process R&D investments (the degrees of reduction of the marginal cost of production) and the costs of such investments. Strategic interplay between firms' R&D decisions concerning innovation benefits and costs lies at the heart of the growing literature on the R&D investment games (Lambertini and Rossini, 1998; Amir et al., 2011a; Amir et al., 2011b; Burr et al., 2013; Sengupta, 2016; Conti and Marini, 2019).

The current paper shed a new light on the R&D investment games by investigating the vertical industrial setting when the raising rivals' cost effect is present. We discovered that the vertically related industry can give rise to the social tensions (fear and greed) between downstream Cournot competitors who can be thereby caught in the prisoner's dilemma. Luckily, this prisoner's dilemma can work to the benefit of consumers, since fear and greed make firms invest in process R&D and innovate, leading to the consumer welfare enhancements.

Downstream competitors do not however always decide to engage in process R&D in the considered market setup. When the downstream firms are not R&D-efficient enough, they participate in the harmony game resulting in the mutual restraint in R&D investments. Such a scenario can effectively disadvantage consumers compared with the cases when firms engage in R&D (prisoner's dilemma and deadlock cases). Harmony game creates also a space for the formation of the downstream R&D-avoiding cartel.

This paper shows that the downstream firms can have incentives to collude and jointly curtail process R&D. Such an R&D cooperation between firms is however in contradiction with the modern innovation policies which encourage the interfirm R&D cooperation, since the latter usually promotes innovation and consumer welfare (Kamien et al., 1992; Amir et al., 2011b). The R&D-curtailing cooperation is against the objectives of the modern innovation policy, since the R&D-avoiding agreements do not serve the industrial innovation or the consumer welfare. The antitrust authorities should thus carefully distinguish between the R&D-promoting and the R&D-avoiding forms of interfirm cooperation, and outlaw the latter.

The possible extensions of the paper embrace the consideration of different types of downstream competition. The downstream rivalry does not have to follow Cournot competition, the quantity leadership or price competition are also possible. Upstream competition can be introduced. Further, the case of product innovations can be considered. Finally, we can also think of a general model which takes account of *N* downstream firms, not just the duopoly.

References

Aghion, P., Bloom, N., Blundell, R., Griffith, R., Howitt, P. (2005). Competition and innovation: an inverted-U relationship. *Quarterly Journal of Economics, 120*, 701–728.

Amir, R., Halmenschlager, C., Jin, J. (2011a). R&D-induced industry polarization and shake-outs. *International Journal of Industrial Organization, 29*, 386–398.

Amir, R., Garcia, F., Halmenschlager, C., Pais, J. (2011b). R&D as a Prisoner's Dilemma and R&D-avoiding Cartels. *The Manchester School, 79*, 81–99.

d'Aspremont, C., Jacquemin, A. (1988). Cooperative and Noncooperative R&D in Duopoly with Spillovers. *American Economic Review, 78*, 1133–1137.

Atallah, G. (2002). Vertical R&D spillovers, cooperation, market structure, and innovation. *Economics of Innovation and New Technology, 11*, 179–209.

Banerjee, S., Lin, P. (2003). Downstream R&D, raising rivals' costs, and input price contracts. *International Journal of Industrial Organization, 21*, 79–96.

Belderbos, R., Gilsing, V., Lokshin, B., Carree, M., & Sastre, J. (2018). The antecedents of new R&D collaborations with different partner types: On the dynamics of past R&D collaboration and innovative performance. *Long Range Planning, 51*, 285–302.

Bernes, H., Flo, I., Foros, O., Kind, H. (2019). Raising rivals' costs or improving efficiency? An exploratory study of managers' views on backward integration in the grocery market. *Journal of Revenue and Pricing Management, 18*, 65–75.

Brams, S. (1992). A generic negotiation game. *Journal of Theoretical Politics, 4*, 53–66.

Burr, C., Knauff, M., Stepanova, A. (2013). On the prisoner's dilemma in R&D with input spillovers and incentives for R&D cooperation. *Mathematical Social Sciences, 66*, 254–261.

Choi, J., Yi, S. (2000). Vertical Foreclosure with the Choice of Input Specifications. *RAND Journal of Economics, 31*, 717–743.

Coase, R. (1976). *Adam Smith's View of Man*. The University of Chicago Selected Papers No. 50.

Conti, C., Marini, M. (2019). Are you the right partner? R&D agreement as a screening device. *Economics of Innovation and New Technology, 28*, 243–264.

Curtis Eaton, B. (2004). The elementary economics of social dilemmas. *Canadian Journal of Economics, 37*, 805–829.

Dai, R., Zhang, J., Tang, W. (2017). Cartelization or Cost-sharing? Comparison of cooperation modes in a green supply chain. *Journal of Cleaner Production, 156*, 159–173.

Dasgupta, P. (1986). *The Theory of Technological Competition*. In: Stiglitz, J., Mathewson, G. (eds), *New Developments in the Analysis of Market Structure*. International Economic Association Series, vol. 77, London: Palgrave Macmillan.

DeCanio, S., Fremstad, A. (2013). Game theory and climate diplomacy. *Ecological Economics, 85*, 177–187.

Dertwinkel-Kalt, M., Haucap, J., Wey, C. (2015). Raising rivals' cost through buyer power. *Economics Letters, 126*, 181–184.

Farahani, M., Sheikhmohammady, M. (2014). A review on symmetric games: theory, comparison and applications. *International Journal of Applied Operational Research, 4*, 91–106.

Ge, Z., Hu, Q., Xia, Y. (2014). Firms' R&D Cooperation Behavior in a Supply Chain. *Production and Operations Management, 23*, 599–609.

Geroski, P. (1992). Vertical relations between firms and industrial policy. *Economic Journal, 102*, 138–151.

Hansel, M., Mutschler, M., Dickow, M. (2018). Taming cyber warfare: lessons from preventive arms control. *Journal of Cyber Policy, 3*, 44–60.

Harabi, N. (2002). The impact of vertical R&D cooperation on firm innovation: An empirical investigation. *Economics of Innovation and New Technology, 11*, 93–108.

Hortacsu, A., Syverson, C. (2007). Cementing relationships: Vertical integration, foreclosure, productivity, and prices. *Journal of Political Economy, 115*, 250–301.

Inkmann, J. (2000). Horizontal and vertical R&D cooperation. Center of Finance and Econometrics at the University of Konstanz, discussion paper 02/2000.

Ishii, A. (2004). Cooperative R&D between vertically related firms with spillovers. *International Journal of Industrial Organization, 22*, 1213–35.

Jullien, B., Reisinger, M., Rey, P. (2018). Vertical foreclosure and multi-segment competition. *Economics Letters, 169*, 31–34.

Kamien, M., Muller, E., Zang, I. (1992). Research Joint Ventures and R&D Cartels. *American Economic Review, 82*, 1293–1306.

Kamien, M., Zang, I. (2000). Meet me halfway: research joint ventures and absorptive capacity. *International Journal of Industrial Organization, 18*, 995–1012.

Karbowski, A. (2019). Cooperative and non-cooperative R&D in product innovation and firm performance. *Journal of Business Economics and Management, 20*, 1121–1142.

Lambertini, L., Rossini, G. (1998). Product homogeneity as a prisoner's dilemma in a duopoly with R&D. *Economics Letters, 58*, 297–301.

Manasakis, C., Petrakis, E., Zikos, V. (2014). Downstream Research Joint Venture with Upstream Market Power. *Southern Economic Journal, 80*, 782–802.

Marshall, G., Parra, A. (2019). Innovation and competition: The role of the product market. *International Journal of Industrial Organization, 65*, 221–247.

Ordover, J., Saloner, G., Salop, S. (1990). Equilibrium Vertical Foreclosure. *American Economic Review, 80*, 127–142.

Płatkowski, T. (2017). Greed and fear in multiperson social dilemmas. *Applied Mathematics and Computation, 308*, 157–160.

Rusch, H. (2019). The evolution of collaboration in symmetric 2x2 games with imperfect recognition of types. *Games and Economic Behavior, 114*, 118–127.

Salinger, M. (1988). Vertical Mergers and Market Foreclosure. *Quarterly Journal of Economics, 77*, 345–356.

Salop, S., Scheffman, D. (1983). Raising rivals' costs. *American Economic Review, 73*, 267–271.

Salop, S., Scheffman, D. (1987). Cost-raising strategies. *The Journal of Industrial Economics, 36*, 19–34.

Sengupta, A. (2016). Investment secrecy and competitive R&D. *The B.E. Journal of Economic Analysis & Policy, 16*, 1573–1583.

Wakeley, J., Nowak, M. (2019). A two-player iterated survival game. *Theoretical Population Biology, 125*, 38–55.

Xu, L., Liang, D., Duan, Z., Xiao, X. (2015). Stability Analysis of R&D Cooperation in a Supply Chain. *Mathematical Problems in Engineering*, Article ID 409286.

 DOI: 10.7206/DEC.1733-0092.131