Trade Secrets and Research Joint Ventures

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Abstract

This paper focuses on industries, where patent protection is weak and innovations are commonly protected as trade secrets. It is shown that if potential innovations are major, but the chances of achieving a successful innovation are small, then Cournot duopolists prefer to keep their innovations trade secrets. Otherwise, if potential innovations are minor or the chances of success are large, the duopolists prefer to form a research joint venture.

Key Words: trade secrets, research joint ventures, research and development, Cournot competition.

JEL Classification: L13, L24, O31.

1 Introduction

There are two major mechanisms to protect an innovation: patents and trade secrets. From a practical perspective, each mechanism is rich in detail and so its applicability and costs vary from industry to industry. From the perspective of economic theory, however, these mechanisms are the same but for one important difference – patent protection implies that the occurrence of an innovation, together with all its details, is public knowledge, whereas with trade secrets such information remains, at least partially, private.

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Consider, specifically, cost reducing innovations. Under patent protection all the competitors are aware of each others' innovations and so are aware of each others' cost reductions. New computer hardware is one example: the innovations are protected by patents, which are publicly available from the moment of application, and the costs of producing a specific item are easily assessable, because most components come from third party supplies.[1] On the other hand, under trade secrets the information about each others' costs remains uncertain. For example, Google keeps its search algorithms in secret and it is difficult to estimate how much it costs Google to run the corresponding software.[2] A broader example of trade secrets is internal IT and business infrastructures in private companies. What all these examples illustrate is that in general competitors posses different information about each other depending on whether their innovations are protected by patents or as trade secrets. From a theoretical perspective, these informational differences imply that the strategy spaces are different and, consequently, the outcomes of the competition are different as well.

While theoretical analysis of various patent arrangements received much attention in the literature, to the best of my knowledge there is no theoretical work on trade secrets that highlights the aforementioned uncertainty that trade secrets inherently create. The present paper contributes to this open topic.

The outlined difference between patent protection and trade secrets exists only when research and development has uncertain outcomes. The relevant literature on uncertain research and development includes: Reinganum (1990), Combs (1993), Choi (1993), Katsoulacos and Ulph (1998), Martin (2002), Miyagiwa and Ohno (2002), Hauenschild (2003), Erkal and Piccinin (2010). This literature focuses exclusively on innovations, that are public knowledge and can not be copied, or, equivalently, it focuses on patent protection. In contrast, in the present paper I consider innovations that are protected as trade secrets. In particular, I consider quantity-competing duopolists that research into cost reducing innovations and ask the question whether these duopolists prefer to keep their innovations as trade secrets or

[1]For example, isuppli.com regularly publishes costs breakdowns for popular consumer electronics.

[2]To see the ambiguity on Google search algorithms, an interested reader is referred to `http://news.bbc.co.uk/2/hi/7823387.stm`. A US physicist Alex Wissner-Gross did an estimation that a Google search produces 7g of CO_2, while Google responded by saying it was a mere 0.2g.

whether they prefer to form a research joint venture (RJV).

This question is common in the literature on R&D, and the present paper extends the earlier results by addressing the question in the framework of trade secrets. The angle of analysis is also different from the existing literature. The literature on R&D primarily focuses on the difference in effort between private and joint research, and the consequent welfare implications.[3] In this paper the focus is on how the choice between private and joint research is influenced by the characteristics of the R&D process, like the probability of success and the potential impact of successful innovations.

Keeping innovations as trade secrets means that each duopolist does R&D on its own, and if he achieves a cost reducing innovation, his competitor is not aware of it. Forming a research joint venture, on the other hand, implies a twofold change: i) in an RJV the duopolists join their R&D effort, thus raising the chances for success, and they share any consequent innovations; ii) in an RJV, as the duopolists share their innovations, they are automatically aware of each others' cost reductions.

The second effect, in its own right, is well studied in the literature on information sharing: Fried (1984), Li (1985), Gal-or (1986) and Shapiro (1986), all consider Cournot competition with uncertain costs and show that an ex-ante commitment to share the information on those costs is a strictly dominant strategy (with Bertrand competition the results are the opposite – concealing the information is a strictly dominant strategy; I discuss Bertrand competition in more detail in the concluding section).[4]

Arguably, in the industries, where patent protection is weak and innovations are commonly guarded as trade secrets, it is impossible to credibly reveal one's reduction in costs without revealing the corresponding innovation. Therefore, these two effects, (i) and (ii), can not be separated for such industries and shall be studied together. As the present paper demonstrates, the joint analysis of these two effects gives novel results.

The interaction in question is modelled as a two-period game. In period one the firms negotiate whether to form a research joint venture. In period two, if the RJV was formed, the firms observe their mutual cost reductions, otherwise – if the firms chose to conduct their research in private – they observe only their own cost reductions. In either case the firms simultaneously choose how much of the commodity to supply to the market, after that the

[3]Starting with the seminal paper by d'Aspremont and Jacquemin (1988).

[4]See also Kühn and Vives, 1995 for a broader overview of the subject.

price and profits are realized.

Studying subgame perfect Nash equilibria of this game gives the following results. If there is a small chance of a major innovation, then competing firms choose private R&D in period one and guard any consequent innovations as trade secrets. Otherwise – if the chances of an innovation are high, or if any possible innovation is minor at best, or both – then the firms join their R&D effort by forming a research joint venture.

Intuitively, these results can be explained as follows. A posteriori, a firm would prefer a trade secrets arrangement over a joint research one, if the firm itself acquires an innovation while its competitor does not. A priory then, the more profitable and more likely this event of an exclusive innovation is, the more attractive is the trade secrets arrangement. An exclusive innovation is more profitable, if it reduces the costs substantially, i.e. if it is a major innovation. Second, if there is an innovation, it is more likely to be exclusive when the chance of an individual innovation is small. Hence, a small chance of a major innovation favours trade secrets.

The results contrast those of the information sharing literature. As mentioned earlier, Cournot duopolists always prefer to share the information on their costs. In the present model sharing information additionally implies forgoing a possibility to enjoy an exclusive innovation, and, as the formal analysis shows, this consideration is important enough to support equilibria where no information is shared.

The joint research improves efficiency, so it is to be expected it is also welfare improving. The analysis confirms this intuition: RJVs always create higher consumer surplus and higher total welfare than do trade secrets. So, there is a normative implication: in industries where possible innovations are expected to be major but the chances of success are estimated to be small, a subsidy for research joint ventures can be welfare improving.

Finally, the paper compares trade secrets and patents. When there is patent protection, a firm with a successful innovation applies for a patent and thus signals its success to other firm. This signalling reduces the output of the rival, what is not the case when innovations are protected as trade secrets. Consequently, in case of patents ex-ante expected profits of firms are larger than in case of trade secrets, and so in case of patents firms are less likely to form a research joint venture. Whether considering trade secrets or patents, RJVs always deliver the highest welfare. So, there are cases when trade secrets are preferable to patents, because they facilitate joint research.

The paper is organized as follows. Section 2 formally sets up the outlined two-period game. First, the second period is analysed, for the case of trade secrets – section 3, and for the case of a research joint venture – section 4. Second, the first period is analysed to see whether the firms prefer to form an RJV or not, this is done in section 5. Section 6 discusses welfare implications, section 7 looks at how the ealier analysis changes when patent protection is considered, section 8 concludes. Possible extensions of the model – Bertrand competition, dependence of R&D on effort, multiple firms – are addressed in the concluding section.

2 The Model

Particular functional forms are assumed for the demand system, production costs and the distribution of R&D outcomes. Doing so gives a closed form solution to the model, and, consequently, comparative statics are straightforward. It is also a common practice in the literature on R&D as well as the literature on information sharing.

There are two firms, 1 and 2. Let $i \in \{1, 2\}$ denote either firm and let $j = 3 - i$ denote its competitor. Both firms produce a homogeneous good q and compete à la Cournot on the final good market. The inverse demand is given by

$$p(q) = a - bq, \tag{1}$$

where $q = q_1 + q_2$, $a > 0$, $b > 0$.

Each firm i has linear marginal costs. In case of private R&D the costs of firm i are

$$c_i(q_i) = (c - \varepsilon_i)q_i, \tag{2}$$

where ε_i is the random outcome of the firm's private R&D process, $0 \leq c \leq a$, $0 \leq \varepsilon_i \leq c$, and ε_1, ε_2 are independent.

In case of a research joint venture, the costs of either firm are

$$c_i(q_i) = (c - \eta)q_i, \tag{3}$$

where η is the random outcome of the joint R&D process.

Private research and development is modelled as follows. Each firm has a research team, and each team is given a certain amount of time to complete their research agenda. Over this time a team can make cost reducing innovations. The innovation process is a Poisson process with intensity λ. If one or more innovations are made, then one innovation gets implemented.

For simplicity it is assumed that a successful innovation always results in a reduction d of the marginal costs, $d \leq c$. If no innovations are made, there is no reduction of the marginal costs. So, with probability $r = 1 - e^{-\lambda}$ there is a successful innovation and $\varepsilon_i = d$, and with probability $1 - r$ there is no innovation and $\varepsilon_i = 0$.

When the firms join their research and development, they join their research teams and the resulting intensity of the innovation process doubles. Then, with probability $s = 1 - e^{-2\lambda}$ there is a successful innovation and $\eta = d$, and with probability $1 - s$ there is no innovation and $\eta = 0$.

In principal, RJVs can exhibit synergy effects[5] as well as bear coordination costs. Either of those effects, if not too large, will change the quantitative results of the model, but not the qualitative results. Therefore those effects are omitted from the discussion.

While the research and development literature focuses on the amount of effort invested in R&D and whether that amount is socially optimal, the focus of this paper is on the trade off between common knowledge and common innovations (RJVs) on one hand, and private knowledge and private innovations (trade secrets) on the other hand. So, effort considerations are omitted and R&D outcomes are simply modelled as unconditional random variables. The concluding section briefly discusses the question of adding effort to the present model.

There are two periods. In the first period the firms know the demand and have their expectations about the success of their own R&D programs as well as about the success of the joint research, if they are to conduct one. In this period the firms negotiate whether indeed to conduct the joint research. A simple two-stage negotiating procedure is assumed, which guarantees the selection of the most efficient outcome: firm 1 can offer firm 2 to form an RJV or it can make no offer at all; if firm 1 does make the offer, then firm 2 can either accept or reject it; if the offer is made and accepted, then the firms form an RJV, in any other case the firms resort to the trade secrets arrangement.

In the second period all the R&D programs are completed. In case of an RJV, both firms receive the same innovation and so are aware of each others' cost reductions. In case of private R&D each firm observes only the outcome

[5] For example, within the current setup, if two or more innovations are required to achieve the reduction of marginal costs, then there will be additional synergy when forming RJVs.

of its own R&D process, not that of its competitor. At the end of the period the firms simultaneously choose their production levels, to the best of their knowledge.

The final payoff for each firm is its profit and the firms are assumed to be risk neutral.

3 Trade Secrets

This section analyzes the subgame, in which the firms do their own R&D. This subgame starts at the node, where nature moves to determine ε_1 and ε_2.

Once nature has moved, firm i sets its output q_i knowing ε_i, but not knowing ε_j, its expected profits conditional on ε_i are

$$\mathbb{E}(\pi_i^{ts} \,|\, \varepsilon_i) = \mathbb{E}\big((a - b(q_i + q_j) - (c - \varepsilon_i))q_i \,\big|\, \varepsilon_i\big) = \\ \big(a - c + \varepsilon_i - b(q_i + \mathbb{E}(q_j \,|\, \varepsilon_i))\big)q_i = \big(\alpha + \varepsilon_i - b(q_i + \mathbb{E}(q_j))\big)q_i \quad (4)$$

where the notation $\alpha = a - c$ is assumed for convenience and $\mathbb{E}(q_j \,|\, \varepsilon_i) = \mathbb{E}(q_j)$, because q_j depends upon ε_j only and ε_j is independent from ε_i.

Maximizing (4) in q_i gives

$$\hat{q}_i = \max\left(\frac{\alpha + \varepsilon_i}{2b} - \frac{1}{2}\mathbb{E}(q_j),\, 0\right) \quad (5)$$

Potentially, if there is no innovation, i.e. $\varepsilon_i = 0$, and if the expected output of the competitor $\mathbb{E}(q_j)$ is large enough, then it can be that no level of output provides positive profits and it is best to produce nothing. We will see that this corner solution can indeed occur in an equilibrium.

In an equilibrium firm j plays its best response $\hat{q}_j$, therefore in an equilibrium

$$\hat{q}_i = \max\left(\frac{\alpha + \varepsilon_i}{2b} - \frac{1}{2}\mathbb{E}(\hat{q}_j),\, 0\right) \quad (6)$$

Taking an unconditional expectation of both parts gives

$$\mathbb{E}(\hat{q}_i) = \mathbb{E}\left(\frac{\alpha+\varepsilon_i}{2b} - \frac{1}{2}\mathbb{E}(\hat{q}_j) \,\middle|\, \varepsilon_i \geq b\mathbb{E}(\hat{q}_j) - \alpha\right) \cdot \mathbb{P}\big(\varepsilon_i \geq b\mathbb{E}(\hat{q}_j) - \alpha\big) =$$

$$\begin{cases} \dfrac{\alpha+rd}{2b} - \dfrac{1}{2}\mathbb{E}(\hat{q}_j) & \text{if} \quad \mathbb{E}(\hat{q}_j) \leq \dfrac{\alpha}{b} \\ \dfrac{r(\alpha+d)}{2b} - \dfrac{r}{2}\mathbb{E}(\hat{q}_j) & \text{if} \quad \dfrac{\alpha}{b} < \mathbb{E}(\hat{q}_j) \leq \dfrac{\alpha+d}{b} \\ 0 & \text{if} \quad \dfrac{\alpha+d}{b} < \mathbb{E}(\hat{q}_j) \end{cases} \tag{7}$$

As $i \in \{1, 2\}$, equation (7) defines expected best response functions for both firms. Their unique intersection is given by:

$$\mathbb{E}(\hat{q}_i) = \begin{cases} \dfrac{\alpha+rd}{3b} & \text{if} \quad 2\alpha \geq rd \\ \dfrac{r(\alpha+d)}{(r+2)b} & \text{if} \quad 2\alpha < rd \end{cases} \tag{8}$$

Bringing together equations (6) and (8) gives the unique equilibrium strategy for either firm:

$$\hat{q}_i = \begin{cases} \dfrac{2\alpha - rd + 3\varepsilon_i}{6b} & \text{if} \quad 2\alpha \geq rd \\ \max\left(\dfrac{2\alpha - rd + (r+2)\varepsilon_i}{2b(r+2)}, 0\right) & \text{if} \quad 2\alpha < rd \end{cases} \tag{9}$$

If $2\alpha \geq rd$, then both firms participate in the market no matter whether they achieved a successful innovation. If $2\alpha < rd$ on the other hand, i.e. if the maximum size of the market is relatively small in comparison with the expected benefits from the R&D, then only the innovating firms participate in the market (in this case, if $\varepsilon_i = 0$, then $q_i = 0$; if $\varepsilon_i = d$, then $q_i = \frac{\alpha+d}{b(r+2)} > 0$).

Given (9), it is straightforward to calculate expected equilibrium profits:

$$\mathbb{E}(\hat{\pi}_i^{ts}) = \begin{cases} \dfrac{4\alpha^2 + 8\alpha rd + 9rd^2 - 5r^2d^2}{36b} & \text{if} \quad 2\alpha \geq rd \\ \dfrac{r(\alpha+d)^2}{(r+2)^2 b} & \text{if} \quad 2\alpha < rd \end{cases} \tag{10}$$

So, we have the following result:

Proposition 1. *There is a unique Nash equilibrium in the trade secrets subgame. The strategies of the firms are given by* (9) *and the ex-ante expected equilibrium payoffs are given by* (10)*.*

4 Research Joint Venture

This section analyzes the subgame, in which the firms form an RJV. This subgame starts at the node, where nature moves to determine η.

In this subgame the firms share the outcome of their research and development program and therefore no uncertainty is left at the stage of Cournot competition. It is then a straightforward textbook exercise. However, for the sake of completeness, the solution is provided below.

Conditional on η, the expected profits of firm i are

$$\mathbb{E}(\pi_i^{rjv} \,|\, \eta) = \big(\alpha + \eta - b(q_i + \mathbb{E}(q_j \,|\, \eta))\big) q_i \tag{11}$$

Maximizing $\mathbb{E}(\pi_i^{rjv} \,|\, \eta)$ w.r.t. q_i gives

$$\hat{q}_i = \max\left(\frac{\alpha + \eta}{2b} - \frac{1}{2}\mathbb{E}(q_j \,|\, \eta),\, 0\right) \tag{12}$$

and in an equilibrium

$$\hat{q}_i = \max\left(\frac{\alpha + \eta}{2b} - \frac{1}{2}\mathbb{E}(\hat{q}_j \,|\, \eta),\, 0\right) \tag{13}$$

Taking a conditional expectation of both parts gives

$$\mathbb{E}(\hat{q}_i \,|\, \eta) = \max\left(\frac{\alpha + \eta}{2b} - \frac{1}{2}\mathbb{E}(\hat{q}_j \,|\, \eta),\, 0\right) \tag{14}$$

Equation (14) shall hold for $i \in \{1, 2\}$, its unique solution is then

$$\mathbb{E}(\hat{q}_i \,|\, \eta) = \frac{\alpha + \eta}{3b} \tag{15}$$

Hence, using (13),

$$\hat{q}_i = \frac{\alpha + \eta}{3b} \tag{16}$$

Given that $\eta \sim B(1,s) \cdot d$ with $s = 1-(1-r)^2$ and given (16), it is straightforward to calculate expected equilibrium profits in case of a research joint venture:

$$\mathbb{E}(\hat{\pi}_i^{rjv}) = \frac{\alpha^2 + 4\alpha r d + 2rd^2 - 2\alpha r^2 d - r^2 d^2}{9b} \tag{17}$$

So, we have

Proposition 2. *There is a unique Nash equilibrium in the RJV subgame. The strategies of the firms are given by* (16)*, and the ex-ante expected equilibrium payoffs are given by* (17)*.*

5 Trade Secrets vs. RJV

Consider now the whole game. If $\mathbb{E}\pi_i^{rjv} > \mathbb{E}\pi_i^{ts}$, then there is a unique SPNE, in which firm 1 makes the offer of a joint research and firm 2 accepts. If $\mathbb{E}\pi_i^{rjv} < \mathbb{E}\pi_i^{ts}$, then, formally, there are two SPNE: i) firm 1 makes no offer, ii) firm 1 makes a joint research offer and firm 2 rejects. In either case the firms continue in the trade secrets subgame.

We next turn to the comparison of the expected profits. If $r = 0$ or $r = 1$ then, obviously, $\mathbb{E}\pi_i^{ts} = \mathbb{E}\pi_i^{rjv}$. If $0 < r < 1$, then the following proposition holds.

Proposition 3.

$$\mathbb{E}\pi_i^{ts} \gtrless \mathbb{E}\pi_i^{rjv} \Leftrightarrow \frac{\alpha}{d} \lessgtr \begin{cases} \frac{1}{8} & \text{if} \quad 0 < r \leq \frac{1}{4} \\ f(r) & \text{if} \quad \frac{1}{4} < r \leq \frac{\sqrt{13}-3}{2} \\ 0 & \text{if} \quad \frac{\sqrt{13}-3}{2} < r < 1 \end{cases} \tag{18}$$

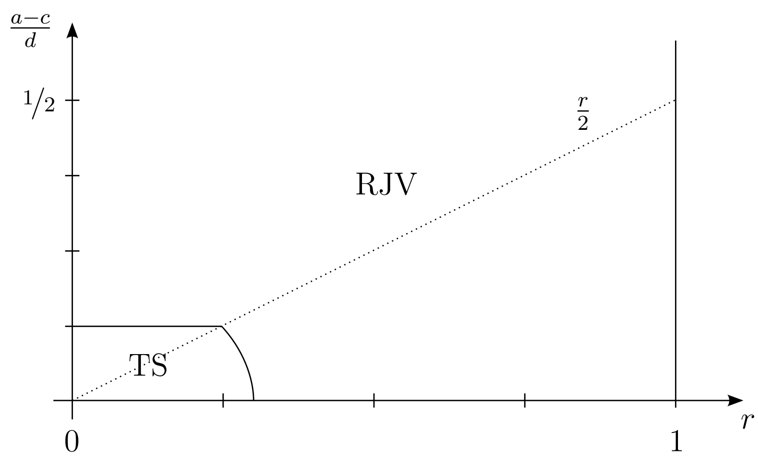
with

$$f(r) = \frac{r(1-3r-r^2) + (2+r)\sqrt{r(1-r)(1-3r-r^2)}}{4-r} \tag{19}$$

The proof is provided in the appendix.

Figure 1 plots the respective regions (recollect that $\alpha = a - c$). Within the trade secrets region (TS), the line $\frac{a-c}{d} = \frac{r}{2}$ separates two cases: above the line

Figure 1: Comparative Statics



both firms participate in the market irrespective of their R&D achievements, below the line only those firms participate in the market that have achieved a successful innovation (see equation 9 and the consecutive notes).

If $\frac{a-c}{d}$ is close to zero then the possible innovation is a *major* one: the costs are close to the maximum size of the market and a successful innovation reduces the costs substantially. On the other hand, if $\frac{a-c}{d}$ is large then the possible innovation is a *minor* one: either it does not reduce the costs much, or the costs are already small comparing to the maximum size of the market. Bringing together this terminology, figure 1 and the above discussion on SPNE delivers

Proposition 4. *When there is small chance of a major innovation the firms do their own R&D, otherwise they form a research joint venture.*

Intuitively, a small chance of a major innovations improves the likelihood of an exclusive innovation in the trade secrets subgame, given there is an innovation, as well as its profitability. Hence, trade secrets become more attractive.

6 Welfare Analysis

It remains to study the choices of the firms from a welfare perspective. As forming an RJV is more likely to be cost reducing, it is to be expected that

RJVs always create higher total welfare than trade secret arrangements. The following formal analysis confirms this intuition.

Consider equilibrium consumer surplus

$$CS = \frac{(a-\hat{P})\hat{Q}}{2} = \frac{b\hat{Q}^2}{2} = \frac{b(\hat{q}_1+\hat{q}_2)^2}{2} \tag{20}$$

Substituting (6), (8) and (16) into (20) and taking expectations gives

$$\mathbb{E}(CS^{ts}) = \begin{cases} \dfrac{8\alpha^2+16\alpha rd+9rd^2-r^2d^2}{36b} & \text{if} \quad 2\alpha \geq rd \\ \dfrac{r(r+1)(\alpha+d)^2}{(r+2)^2b} & \text{if} \quad 2\alpha < rd \end{cases} \tag{21}$$

and

$$\mathbb{E}(CS^{rjv}) = \frac{2(\alpha^2+4\alpha rd+2rd^2-2\alpha r^2d-r^2d^2)}{9b} \tag{22}$$

Consider equilibrium total welfare: $TW = CS + \hat{\pi}_1 + \hat{\pi}_2$. Taking expectations and substituting the respective consumer surpluses and profits gives

$$\mathbb{E}(TW^{ts}) = \begin{cases} \dfrac{16\alpha^2+32\alpha rd+27rd^2-11r^2d^2}{36b} & \text{if} \quad 2\alpha \geq rd \\ \dfrac{r(r+3)(\alpha+d)^2}{(r+2)^2b} & \text{if} \quad 2\alpha < rd \end{cases} \tag{23}$$

and

$$\mathbb{E}(TW^{rjv}) = \frac{4(\alpha^2+4\alpha rd+2rd^2-2\alpha r^2d-r^2d^2)}{9b} \tag{24}$$

The relationship between these expected values is given by

Proposition 5. $\mathbb{E}(CS^{rjv}) > \mathbb{E}(CS^{ts})$ *and* $\mathbb{E}(TW^{rjv}) > \mathbb{E}(TW^{ts})$ *for any* r *such that* $0 < r < 1$.

The proof is provided in the appendix.

So, forming a research joint venture always yields higher consumer surplus and higher total welfare in comparison with trade secrets. At the same time, the firms prefer the trade secrets arrangement when there is a small chance of a major innovation. Consequently, in this latter case a properly designed subsidy for research joint ventures can improve consumer surplus as well at total welfare. This perspective, for example, gives another basis to support governmental subsidies for fundamental research (in this case Cournot competition, when viewed as competition in capacities[6], is more relevant than Bertrand competition, because fundamental research is a long run issue).

7 Patents

This section analyses the case of patent protection of innovations. The questions are analogous to those that we considered earlier in the case of trade secrets. Given patent protection of innovations, when do firms conduct private research and when do they form a research joint venture? What are the consequent consumer and total surpluses?

Additionally, given welfare analysis in case of trade secrets and in case of patents, we can compare these arrangements to one another and answer the following normative question: if innovations in an industry can be protected as trade secrets, shall the government also implement patent protection?

First let us consider the subgame where firms conduct private research. In this subgame the firms choose q knowing both ε_1 and ε_2. The firms know about innovations of their competitors, because any innovation is protected by patents and patents, by definition, are public knowledge. Maximizing the profit function

$$\mathbb{E}(\pi_i^p \mid \varepsilon_i, \varepsilon_j) = \mathbb{E}\big((a - b(q_i + q_j) - (c - \varepsilon_i))q_i \,\big|\, \varepsilon_i, \varepsilon_j\big) = \big(\alpha + \varepsilon_i - b(q_i + \mathbb{E}(q_j \mid \varepsilon_i, \varepsilon_j))\big)q_i \quad (25)$$

in own output q_i gives:

$$\hat{q}_i = \max\left(\frac{\alpha + \varepsilon_i}{2b} - \frac{1}{2}\mathbb{E}(q_j \mid \varepsilon_1, \varepsilon_2),\, 0\right). \quad (26)$$

Compare (26) to (5).

In equilibrium,

$$\hat{q}_i = \max\left(\frac{\alpha + \varepsilon_i}{2b} - \frac{1}{2}\mathbb{E}(\hat{q}_j \mid \varepsilon_1, \varepsilon_2),\, 0\right). \quad (27)$$

[6] On capacities, see, for example, section 5.3 in Tirole (1988).

Solving it for a fixed point gives

$$\hat{q}_i = \begin{cases} \dfrac{\alpha + 2\varepsilon_i - \varepsilon_j}{3b} & \text{if} \quad \alpha \geq d \text{ or } \varepsilon_i = \varepsilon_j \\ \dfrac{\alpha + d}{2b} & \text{if} \quad \alpha < d, \ \varepsilon_i = d, \ \varepsilon_j = 0 \\ 0 & \text{if} \quad \alpha < d, \ \varepsilon_i = 0, \ \varepsilon_j = d \end{cases} \tag{28}$$

If the maximum size of the market minus the costs (α) is smaller than the potential size of an innovation (d), then if one firm is successful in its research while the other firm is not, then only the successful firm participates in the market. This result is similar to what we obtained earlier for the case of trade secrets. Back then we derived that only the successful firms participate if $2\alpha < rd$. Comparing these results shows that monopoly outcomes occur for a larger range of parameters under patents than under trade secrets. Indeed, $2\alpha < rd \Rightarrow \alpha < d$. So we might expect that patents are, in general, less socially desirable that trade secrets. A later proposition 8 confirms this intuition. But to come to that proposition we first need to finish our analysis of the patents subgame.

Plugging $\hat{q}_i$, $\hat{q}_j$ into the profit function and taking expectations gives:

$$\mathbb{E}(\hat{\pi}_i^p) = \begin{cases} \dfrac{\alpha^2 + 2\alpha r d + 5rd^2 - 4r^2d^2}{9b} & \text{if} \quad \alpha \geq d \\ \dfrac{4\alpha^2 + \alpha^2 r + 18\alpha r d + 9rd^2}{36b} + \dfrac{-\alpha^2 r^2 - 10\alpha r^2 d - 5r^2d^2}{36b} & \text{if} \quad \alpha < d \end{cases} \tag{29}$$

So,

Proposition 6. *There is a unique Nash equilibrium in the patents subgame. The strategies of the firms are given by* (28) *and the ex-ante expected equilibrium payoffs are given by* (29).

If the firms agree to form an RJV when there is patent protection, then the analysis is identical to that in section 4 on RJVs.

Once again, to see what the firms agree upon we need to compare their expected profits. Comparing (29) to (17) gives

$$\mathbb{E}(\hat{\pi}_i^p) - \mathbb{E}(\hat{\pi}_i^{rjv}) = \begin{cases} \dfrac{rd(1-r)(3d-2\alpha)}{9b} & \text{if} \quad \alpha \geq d \\ \dfrac{r(1-r)(d+\alpha)^2}{36b} & \text{if} \quad \alpha < d \end{cases} \tag{30}$$

Hence $\mathbb{E}(\hat{\pi}_i^{rjv}) \gtrless \mathbb{E}(\hat{\pi}_i^{p}) \Leftrightarrow \frac{\alpha}{d} \gtrless \frac{3}{2}$. So, we have

Proposition 7. *If there is patent protection of innovations, then firms form a research joint venture if and only if the maximum size of the market minus costs (α) exceeds $\frac{2}{3}d$, where d is the potential size of an innovation.*

Under patent protection firms prefer to form an RJV in fewer cases than under trade secrets (compare propositions 7 and 3). This is so, because patent protection gives a higher chance of capturing the whole market when a firm is acting alone. To look at the welfare side of the story we now turn to total and consumer surpluses.

Doing the same calculations as in earlier section 6 gives:

$$\mathbb{E}(CS^p) = \begin{cases} \dfrac{2\alpha^2 + 4\alpha rd + rd^2 + r^2d^2}{9b} & \text{if} \quad \alpha \geq d \\ \dfrac{8\alpha^2 - 7\alpha^2 r + 18\alpha rd + 9rd^2}{36b} + \dfrac{7\alpha^2 r^2 - 2\alpha r^2 d - r^2 d^2}{36b} & \text{if} \quad \alpha < d \end{cases} \tag{31}$$

and

$$\mathbb{E}(TW^p) = \begin{cases} \dfrac{4\alpha^2 + 8\alpha rd + 11rd^2 - 7r^2d^2}{9b} & \text{if} \quad \alpha \geq d \\ \dfrac{16\alpha^2 - 5\alpha^2 r + 54\alpha rd + 27rd^2}{36b} + \dfrac{5\alpha^2 r^2 - 22\alpha r^2 d - 11r^2 d^2}{36b} & \text{if} \quad \alpha < d \end{cases} \tag{32}$$

Comparing these results against the earlier results on RJV is straightforward:

$$\mathbb{E}(CS^{rjv}) - \mathbb{E}(CS^p) = \begin{cases} \dfrac{rd(1-r)(3d+4\alpha)}{9b} & \text{if} \quad \alpha \geq d \\ \dfrac{7r(1-r)(d+\alpha)^2}{36b} & \text{if} \quad \alpha < d \end{cases} \tag{33}$$

and

$$\mathbb{E}(TW^{rjv}) - \mathbb{E}(TW^p) = \begin{cases} \dfrac{rd(1-r)(8\alpha-3d)}{9b} & \text{if} \quad \alpha \geq d \\ \dfrac{5r(1-r)(d+\alpha)^2}{36b} & \text{if} \quad \alpha < d \end{cases} \tag{34}$$

Hence we have

Proposition 8. $\mathbb{E}(CS^{rjv}) > \mathbb{E}(CS^p)$ *and* $\mathbb{E}(TW^{rjv}) > \mathbb{E}(TW^p)$ *for any* r *such that* $0 < r < 1$.

Now we are ready to compare trade secrets to patents. If $\alpha > d$, then under both regimes firms form a research joint venture and the welfare is maximized. If $\alpha < d$, but innovations are either likely to occur or are relatively minor (see figure 1, RJV region), then under patents firms conduct private research and under trade secrets they form an RJV. The latter option delivers a higher welfare. So in this case, given there is an established practice of keeping innovations as trade secrets, imposing additional laws to protect those innovation with patents will deteriorate welfare. Finally, if there is a small chance of a major innovation, then under both regimes firms conduct private research and the resulting welfare is suboptimal, properly designed subsidies for joint research will be welfare improving.

A word of caution ought to be said: the outlined analysis takes effort as exogenous, so it does not compare how trade secrets, patents or research joint ventures influence the amount of effort that gets allocated towards R&D. How much the results can change if effort is endogenized is briefly discussed in the conclusions.

8 Conclusions

When it comes to the study of joint research ventures, most literature focuses on patent protection of innovations. This paper provided an alternative perspective on joint research ventures by studying innovations that are protected as trade secrets.

It is shown that Cournot duopolists prefer to form research joint ventures when potential innovations are minor, or when the chances of a success are high, or both. However, if there is a small chance of a major innovation, then they prefer to conduct R&D in private and keep any consequent innovations trade secrets. From a welfare perspective, research joint ventures are always better. This result implies that a subsidy for Cournot industries, where there are small chances of major innovations, can be welfare improving.

Additionally, in certain cases a practice of protecting innovations as trade secrets is better from a welfare perspective than patent protection, because trade secrets facilitate joint research more than patents do.

As the present paper raises a relatively new issue, many questions automatically appear. In particular, there is a question how trade secrets would compare against research joint ventures in other settings? Next I discuss three possible extensions: differentiated Bertrand, effort, and multiple firms.

Considering differentiated Bertrand would require a new demand setting, the technical analysis would be similar, but more importantly the intuition is straightforward. If the goods are highly differentiated, then both firms are essentially local monopolists, they do not suffer from each other cost reducing innovations, hence they will prefer to form a research joint venture to maximize the chance of a successful innovation. On the other hand, the less differentiation there is between the goods, the more profitable trade secrets become. At the extreme, if the goods are identical, then the profits are zero unless one firm gets an exclusive innovation, hence in this case trade secrets are chosen over joint research.

Adding effort is technically involving. Even within this simple framework of linear demand and constant marginal costs, if to link the chance of an innovation or its size to effort and if to include quadratic effort costs, the resulting expressions are polynomials of sixth degree (because of the extra optimization step). However, one important, though trivial observation can still be made. The expected profits are continuous in r and d, therefore, if effort changes the initial r or d but only to a limited extent, then the qualitative results will not change. The only change will be in the shape of the indifference curve – those initial r and d, where trade secrets and a research joint venture yield the same expected profits. A preliminary analysis shows that this change is ambiguous – it is not the case that having effort unanimously facilitates either trade secrets or joint research.

Considering multiple firms is a complex problem. If there are n symmetric firms, then there are $n+1$ possible events: nobody innovates, one innovates, etc. The consequent analysis of best responses is technically involved. Additionally, multiple firms bring the issue of different coalition sizes. Strictly speaking, one needs to consider every division of n firms into k RJV coalitions with n_i members each, i.e. $n = n_1 + \ldots + n_k$ and study the incentives of any of those RJV coalitions to merge. Alternatively, networks of bilateral contracts can be used as a basis to study research collaborations among multiple firms, see, e.g. Goyal and Moraga-González (2001). Intuitively, I expect that larger number of firms will favour research joint ventures: with multiple firms there is a smaller chance of an exclusive innovation and hence the trade secrets arrangement will be less attractive.

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Appendix

Proposition 3.

$$\mathbb{E}\pi_i^{ts} \gtreqless \mathbb{E}\pi_i^{rjv} \Leftrightarrow \frac{\alpha}{d} \lesseqgtr \begin{cases} \frac{1}{8} & \textit{if} \quad 0 < r \leq \frac{1}{4} \\ f(r) & \textit{if} \quad \frac{1}{4} < r \leq \frac{\sqrt{13}-3}{2} \\ 0 & \textit{if} \quad \frac{\sqrt{13}-3}{2} < r < 1 \end{cases} \tag{35}$$

with

$$f(r) = \frac{r(1-3r-r^2) + (2+r)\sqrt{r(1-r)(1-3r-r^2)}}{4-r} \tag{36}$$

Proof. Let us first consider the case when $\frac{\alpha}{d} \geq \frac{r}{2}$. In figure 1 the corresponding region is the one above the dotted line. In this case, according to (10) and (17),

$$\mathbb{E}(\hat{\pi}_i^{ts}) = \frac{4\alpha^2 + 8\alpha rd + 9rd^2 - 5r^2d^2}{36b}, \tag{37}$$

$$\mathbb{E}(\hat{\pi}_i^{rjv}) = \frac{\alpha^2 + 4\alpha rd + 2rd^2 - 2\alpha r^2 d - r^2d^2}{9b}. \tag{38}$$

Therefore $\mathbb{E}(\hat{\pi}_i^{ts}) \gtreqless \mathbb{E}(\hat{\pi}_i^{rjv})$ if and only if

$$4\alpha^2 + 8\alpha rd + 9rd^2 - 5r^2d^2 \gtreqless 4\alpha^2 + 16\alpha rd + 8rd^2 - 8\alpha r^2 d - 4r^2d^2$$
$$\Leftrightarrow \quad (d - 8\alpha)(1-r) \gtreqless 0 \quad \Leftrightarrow \quad \frac{\alpha}{d} \lesseqgtr \frac{1}{8}. \tag{39}$$

Hence, when $\frac{\alpha}{d} \geq \frac{r}{2}$, we have TS and RJV regions as depicted in figure 1. Notice that the line $\frac{\alpha}{d} = \frac{1}{8}$ intersects the line $\frac{\alpha}{d} = \frac{r}{2}$ at $r = \frac{1}{4}$.

Consider now the case when $\frac{\alpha}{d} < \frac{r}{2}$. The corresponding region lies below the dotted line in the figure. In this case $\mathbb{E}(\hat{\pi}_i^{rjv})$ is still give by (38) and

$$\mathbb{E}(\hat{\pi}_i^{ts}) = \frac{r(\alpha + d)^2}{(r+2)^2 b}. \tag{40}$$

So, $\mathbb{E}(\hat{\pi}_i^{ts}) \gtrless \mathbb{E}(\hat{\pi}_i^{rjv})$ if and only if

$$\frac{r(\alpha + d)^2}{(r+2)^2 b} \gtrless \frac{\alpha^2 + 4\alpha r d + 2rd^2 - 2\alpha r^2 d - r^2 d^2}{9b}. \tag{41}$$

Let $x = \frac{\alpha}{d}$. Using this substitution and rearranging the terms gives

$$\left(9r - (2+r)^2\right) x^2 + \left(9r - r(2-r)(2+r)^2\right)(2x+1) \gtrless 0. \tag{42}$$

This a quadratic expression in x. The roots are

$$x_{1,2} = \frac{\mp r(1 - 3r - r^2) + (2+r)\sqrt{r(1-r)(1-3r-r^2)}}{4-r}. \tag{43}$$

The coefficient at x^2 is always negative for $0 < r < 1$, hence the LHS of (42) is positive if and only if $x_1 < x < x_2$. Figure 2 plots x_1 and x_2 as functions of r. For $r > \frac{\sqrt{13}-3}{2} \approx 3.03$ the roots are imaginary, so the LHS < 0. Otherwise the LHS is positive within the "circle" and negative outside. Of course, we are only interested in the region, where $0 < x < \frac{r}{2}$.

To combine this case with the earlier case, where $\frac{\alpha}{d} \geq \frac{r}{2}$, recollect that the boundary delimiting TS and RJV crossed the line $\frac{\alpha}{d} = \frac{r}{2}$ at point $\left(\frac{\alpha}{d} = \frac{1}{8}, r = \frac{1}{4}\right)$. It is straightforward to verify that this point belongs to $x_2(r)$, hence the boundary is continuous when crossing $\frac{\alpha}{d} = \frac{r}{2}$. Consequently, the regions for TS and RJV are as they are depicted in figure 1. Combining figure 1 with the above analytical expressions gives the proposition.

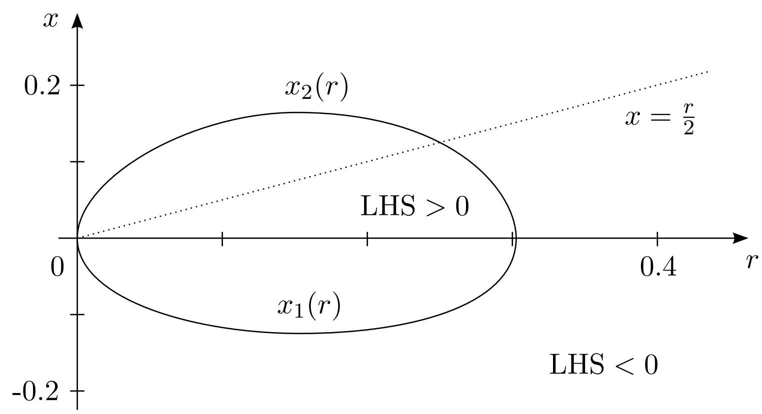
□

Proposition 5. *$\mathbb{E}(CS^{rjv}) > \mathbb{E}(CS^{ts})$ and $\mathbb{E}(TW^{rjv}) > \mathbb{E}(TW^{ts})$ for any r such that $0 < r < 1$.*

Proof. Suppose $\frac{\alpha}{d} \geq \frac{r}{2}$. In this case

$$\mathbb{E}(CS^{rjv}) - \mathbb{E}(CS^{ts}) = \frac{rd(1-r)(7d + 16\alpha)}{36b} \tag{44}$$

Figure 2: Contour plot for the LHS of (42)



and

$$\mathbb{E}(TW^{rjv}) - \mathbb{E}(TW^{ts}) = \frac{rd(1-r)(5d+32\alpha)}{36b}. \tag{45}$$

Clearly then, $\mathbb{E}(CS^{rjv}) > \mathbb{E}(CS^{ts})$ and $\mathbb{E}(TW^{rjv}) > \mathbb{E}(TW^{ts})$ given that $0 < r < 1$.

Suppose $\frac{\alpha}{d} < \frac{r}{2}$. In this case

$$\mathbb{E}(CS^{rjv}) - \mathbb{E}(CS^{ts}) = \frac{(1-r)(8\alpha^2 + 7\alpha^2 r + 14\alpha rd + 12\alpha r^2 d + 4\alpha r^3 d + 7rd^2 + 6r^2d^2 + 2r^3d^2)}{9b(r+2)^2} \tag{46}$$

and

$$\mathbb{E}(TW^{rjv}) - \mathbb{E}(TW^{ts}) = \frac{(1-r)(16\alpha^2 + 5\alpha^2 r + 10\alpha rd + 24\alpha r^2 d + 8\alpha r^3 d + 5rd^2 + 12r^2d^2 + 4r^3d^2)}{9b(r+2)^2} \tag{47}$$

As before, these differences are clearly positive for $0 < r < 1$, hence $\mathbb{E}(CS^{rjv}) > \mathbb{E}(CS^{ts})$ and $\mathbb{E}(TW^{rjv}) > \mathbb{E}(TW^{ts})$.

□