R&D in transport and communication in a Cournot duopoly

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Abstract

We analyse R&D activity in transport and communication technology (TCRD), in a Cournot duopoly. Transport and communication costs are of the iceberg type, i.e., using up some portion of the product along its path to the final buyer. Firms invest in TCRD to increase the net amount of the product that reaches consumers. A variety of equilibria arise as a result of the different levels of TCRD efficiency. If TCRD's productivity is high, the game is a prisoner's dilemma where both firms invest in TCRD.

As the efficiency of the TCRD progressively fades we come across first a chicken game and, then, at lower efficiency, a game with an equilibrium in dominant strategies where the profits are at the highest. Social welfare is maximised by market strategies only when TCRD is very efficient.

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1 Introduction

By and large, R&D expenditure can be devoted either to process or to product innovation. In most of the cases product innovation decreases the degree of substitutability between rival products in oligopolies. No matter which firm engages in product innovation there is a beneficial effect also on rivals that find competing products less close. Literature has emphasized the different degree of efficiency of process innovating R&D in a Cournot market setting vis à vis a Bertrand setting (Brander and Spencer, 1983; Dixon, 1985). Recently Lambertini and Rossini (1998, 1999) and Lambertini et al. (1998) have shown that R&D in product innovation may give rise to the choice of no heterogeneity as a result of a prisoner's dilemma, no matter whether Bertrand or Cournot competition is assumed. This appears to be quite consistent with the externality brought about by product innovation through its effect on substitutability.

To be precise, other kinds of R&D activities may be considered. Casual observation suggests that firms invest in R&D that is neither devoted to product innovation nor to process innovation, yet it is a kind of R&D that allows firms to reach markets in a more efficient way and be more competitive just in their serving customers. The activities involved concern mainly transport and communication needed to let the product reach the final consumer. The related R&D may be figured out as an expenditure that is going to improve the technology of the last stage of the production process. Belong to this category the investment in the Internet, in more advanced logistics, or in faster transport technology. We define this sort of activity transport and communication R&D (TCRD). Most of the times transport and communication services are modeled as if a portion of the output is used up to produce them, while only a fraction of the …nal product is …nalised to the consumer. In such a framework, the purpose of investing in TCRD is just to reduce this chunk of product lost while approaching the …nal buyer.

We borrow from trade theory (see, e.g., Helpman and Krugman, 1985) the modeling of transport and communication costs, assuming that they are of the iceberg type: a quantity q_i of product i is produced, yet only a fraction t 2]0; 1] of the product reaches the consumer. This fraction depends on the investment policy of the …rm, since, by committing to TCRD a …rm may increase it. In doing so the …rm indirectly reduces production costs while making rival products virtually come closer, even though they remain homogeneous. Investing in TCRD is then somehow similar to investing in product innovation R&D, but with an opposite e¤ect, as far as substitutability is concerned. TCRD has a further e¤ect similar to that of process innovation R&D. Investing in TCRD is then a sort of combination of process and, reversed, product innovating R&D.

Our aim is to analyse in a Cournot setting various scenarios in which …rms behave symmetrically or asymmetrically as to TCRD. Our …ndings can be summarised as follows. At the subgame perfect equilibrium, …rms invest in TCRD only if the resulting increase in e¢ciency is large enough. This game is a prisoner's dilemma. When the equilibrium e¢ciency level of the transportation technology is lower, …rms do not invest, which con‡icts with social incentives. From a policy standpoint, a remedy could consist in providing …rms with a subsidy to TCRD. As the e¢ciency of TCRD becomes negligible, investment in TCRD appears undesirable both from a private and from a social standpoint.

The paper is organized as follows. In the next section we analyse the choice between investing in TCRD and not investing. In section 3 we go through the reduced form of the game played by firms. In section 4 we provide the welfare evaluation of the market solutions. Final remarks are in section 5.

2 The model

We analyse a duopoly where firms i and j compete in a two stage framework in a Cournot setting. In the first stage they decide whether to invest either in TCRD or not to invest. The second stage is the market stage. We resort to backward induction to solve the game and get subgame perfection. The R&D strategy space is given by the binary choice between undertaking TCRD or doing nothing $\{0; k\}$; with capital expenditure in TCRD represented by $k > 0$: We assume, for the sake of simplicity, that, if the firm invests in TCRD she will be able to ship the entire product to her customers and no portion will be lost in the way $(t = 1)$. Otherwise, if she doesn't invest in TCRD she will be able to ship only a fraction $t \in]0; 1]$ of the product. Marginal production cost is assumed constant and equal to c:

In a Cournot duopoly setting we consider 3 cases.

2.1 Only one firm invests in TCRD (case a)

Firm i invests in TCRD while firm j does not. Firm i is able to deliver the entire product to her customers, while firm j affords only a portion $t \in]0; 1[$ of the product to reach the consumer after its production, since $1 - t$ is used up in transport and communication due to an inferior technology. We assume linear market demand for the two homogeneous products with a unitary reservation price. Then we have:

$$p = 1 - q_i - tq_j \tag{1}$$

Operative profits are respectively:

$${}^a\pi_i = q_i(1 - q_i - q_j t) - cq_i \tag{2}$$

$${}^a\pi_j = tq_j(1 - q_i - q_j t) - cq_j. \tag{3}$$

From market stage first order conditions (FOCs),[1] we get the following quantities:

$${}^a q_i^* = \frac{c + t - 2ct}{3t}$$

$${}^a q_j^* = \frac{-2c + t + ct}{3t^2}.$$

Equilibrium total profits are:

$${}^a\pi_i^* = \frac{(2ct - c - t)^2}{9t^2} - k \tag{4}$$

$${}^a\pi_j^* = \frac{(ct - 2c + t)^2}{9t^2}. \tag{5}$$

2.2 Both firms invest in TCRD (case b)

Assume firms i and j invest in TCRD. Operative profits are

$${}^b\pi_i = q_i(1 - q_i - q_j) - cq_i \tag{6}$$

[1] Second order conditions are always satisfied, as it may be easily checked in this and subsequent cases.

$$ {}_b\pi_j = q_j(1 - q_i - q_j) - cq_j. \tag{7} $$

Equilibrium quantities are:

$$ {}_b q_i^* = {}_b q_j^* = \frac{1 - c}{3} $$

and equilibrium profits are:

$$ {}_b\pi_i^* = {}_b\pi_j^* = \frac{(1 - c)^2}{9} - k. \tag{8} $$

2.3 None invests in TCRD (case c)

Assume that neither firm i nor firm j invests in TCRD. Operative profits become:

$$ {}_c\pi_i = tq_i(1 - tq_i - tq_j) - cq_i \tag{9} $$

$$ {}_c\pi_j = tq_j(1 - tq_i - tq_j) - cq_j. \tag{10} $$

Equilibrium quantities are:

$$ {}_c q_i^* = {}_c q_j^* = \frac{t - c}{3t^2} \tag{11} $$

while equilibrium total profits are

$$ {}_c\pi_i^* = {}_c\pi_j^* = \frac{(c - t)^2}{9t^2}. \tag{12} $$

In case d, firm i does not invest in TCRD, while firm j does. Therefore we just obtain the reversed payoffs of case a, i.e.: ${}_a\pi_i^* = {}_d\pi_j^*$ and ${}_d\pi_i^* = {}_a\pi_j^*$.

3 The reduced form of the game

The reduced form of the game is represented in normal form in matrix 1.

		firm j	
		0	k
firm i	0	${}^c\pi_i^* = {}^c\pi_j^*$	${}^d\pi_i^*;\ {}^d\pi_j^*$
	k	${}^a\pi_i^*;\ {}^a\pi_j^*$	${}^b\pi_i^* = {}^b\pi_j^*$

Matrix 1

The above game has different solutions according to the productivity of TCRD. By partitioning the admissible set of k into three regions, we can derive the following:

Proposition 1 When TCRD is very efficient, i.e., at the lower bound of the feasible set of $k \in \left(0; \frac{4c(c-t)(t-1)}{9t^2} = k_1\right]$; the game is a prisoner's dilemma with a unique solution in dominant strategies and both firms invest in TCRD.

As TCRD becomes less efficient, i.e., for $k \in \left[k_1; \frac{4ct(1-c)(1-t)}{9t^2} = k_2\right]$; the game becomes a chicken game and there exist two asymmetric equilibria in which only one firm invests in TCRD.

For all $k \in [k_2; \infty)$; the game has an equilibrium in dominant strategies where the aggregate payoff of the firms is maximized by not investing in TCRD. Such an equilibrium is Pareto-efficient from the firms' standpoint.

Proof. First consider non-negativity constraints on quantities. In case a) we have that $q_i^* \geq 0$ if $t \geq \frac{c}{2c-1}$ and $q_j^* \geq 0$ if $t \geq \frac{2c}{1+c}$. If we compare the two threshold levels of t we find that, if $1/2 < c < 1$, then $\dfrac{2c}{1+c} < \dfrac{c}{2c-1}$. Therefore, in order to have $q_{i,j} > 0$, it must be $t > \dfrac{c}{2c-1}$. While if $c \in [0, 1/2)$ the condition turns out to be $t > \dfrac{2c}{1+c}$.

In case b) the same requirement boils down simply to $c \leq 1$, while in case c) it becomes $t \geq c$.

Taking into account the above constraints on the parameters, we compare the payoffs appearing in matrix 1.

First, we can see that ${}_c\pi^*_{i,j} \geq {}_b\pi^*_{i,j}$, since

$$\frac{(1-c)^2}{9t^2} \geq \frac{(1-c)^2}{9} - k.$$

Then compare ${}_b\pi^*_{i,j}$ with ${}_a\pi^*_j$. We see that

$${}_b\pi^*_{i,j} \geq {}_a\pi^*_j$$

if

$$k \leq \frac{4c(c-t)(t-1)}{9t^2} = k_1. \tag{13}$$

Third, compare ${}_a\pi^*_i$ with ${}_c\pi^*_{i,j}$. It appears that ${}_a\pi^*_i \geq {}_c\pi^*_{i,j}$ if

$$k \leq \frac{4ct(1-c)(1-t)}{9t^2} = k_2. \tag{14}$$

Eventually, if we compare k_1 with k_2 we see that:

$$k_1 - k_2 < 0$$

in the admissible region of parameters. Therefore:

i) if $0 < k \leq k_1$ the sequence of payoffs becomes

$${}_a\pi^*_i \geq {}_c\pi^*_{i,j} \geq {}_b\pi^*_{i,j} \geq {}_a\pi^*_j$$

and the game is a prisoner's dilemma with a unique equilibrium where both firms invest in TCRD.

ii) if $k_1 \leq k \leq k_2$ the sequence of payoffs is

$$a\pi^*_j \geq c\pi^*_{i;j} \geq a\pi^*_i \geq b\pi^*_{i;j}$$

and the game is a chicken game with two equilibria off the principal diagonal, where only one firm alternatively invests in TCRD.

iii) if $k \geq k_2$ the sequence of payoffs becomes

$$b\pi^*_{i;j} \geq a\pi^*_j \geq a\pi^*_i \geq c\pi^*_{i;j}$$

and the game has a unique equilibrium in which none of the firms invests in TCRD, and the aggregate payoffs of the firms is maximized. It can be easily checked that the sequence of payoffs presented is invariant as the value of the parameter c varies within its admissible range. ■

4 Welfare analysis

If we now go to the welfare assessment, we can state the following:

Proposition 2 The solution of the TCRD game is also the outcome preferred by the social planner when the efficiency of TCRD is high and both firms invest, i.e., case b: For lower levels of TCRD efficiency, i.e., for larger k; the social planner may prefer firms not to invest. At intermediate levels of k firms do not invest while the social planner would like them all to do so.

Proof. We start calculating the social welfare in the three cases $a; b; c$:

In case a) the consumer surplus is:

$$cs_a = \frac{(c - 2t + ct)^2}{18t^2}$$

while social welfare, defined as the sum of consumer surplus and profits is:

$$sw_a = \frac{c^2(11 - 14t + 11t^2) - 8t(c - t + ct)}{18t^2} - k$$

In case b) both firms invest in TCRD and then we get:

$$cs_b = 2\left(\frac{1 - c}{3}\right)^2$$

while social welfare is

$$sw_b = \frac{2(2 - 4c + 2c^2)}{9} - k.$$

In case c) we have:

$$cs_c = 2\left(\frac{c - t}{3t}\right)^2$$

while social welfare is

$$sw_c = \frac{4(c - t)^2}{9t^2}.$$

Compare first sw_b with sw_c and substitute k_1 to k. It then appears that $sw_b > sw_c$ if $(t - 1)(1 - c) < 0$, that is always true. If we substitute k_2 for k we end up with $(t - c)(t - 1) < 0$; that is always true, since feasibility requires $1 > t > c$. This establishes that, for all $k \in [0, k_2]$, $sw_b > sw_c$.

Now compare sw_a with sw_c. It appears that $sw_a > sw_c$ if

$$c^2(11 - 14t + 11t^2) - 8t(c - t + ct) - 18t^2k > 8(c - t)^2$$

If we substitute k_1 in the above expression it appears that it is always true in the feasible set of parameters. The same happens if we substitute k_2.

Then compare sw_b with sw_a. It appears that $sw_b > sw_a$ regardless of the value of k. To prove it just use the feasibility condition that $t > c$.

Therefore the outcome preferred by the social planner is that associated with both firms investing in TCRD. This coincides with the equilibrium of the game played by firms, if TCRD is very efficient, i.e. for $k \in [0; k_1]$: The coincidence disappears for $k_1 > k > k_2$ since firms face a chicken game, while the social planner would like them all to invest.

When we consider values of k larger than k_2; the evaluations of the social planner change. While $sw_b > sw_a$ regardless of the value of k; we find that $sw_c > sw_b$ if $k > k_4 = \frac{ct^2 - 2t^2 - c + 2t}{9t^2}$ and $sw_c > sw_a$ if $k > k_3 = \frac{c^2(11 - 14t + 11t^2) - 8t(c - t + ct) - 8(c - t)^2}{18t^2}$: By comparing k_4 and k_3 we see that $k_4 > k_3$ if $t > \frac{11c}{8 + 3c}$: Mind that $\frac{11c}{8 + 3c} < \frac{c}{2c - 1} < \frac{2c}{1 + c}$ for all feasible $c < t \in]0; 1]$: Then for $k_2 > k > k_3$ firms do not invest in TCRD while the planner would like them to invest. For $k_3 > k > k_4$ the same applies, while beyond k_4 the planner agrees with the firms and prefers them not to invest since it is socially too expensive. ■

We have seen that for intermediate levels of TCRD commitment the social planner would like firms to invest. Therefore, there is a case for public subsidies to TCRD whenever the cost of TCRD is not too high.

5 Concluding remarks

We have analysed in a simple Cournot duopoly setting the choice of firms to undertake a particular kind of R&D, that has not been considered so far in the literature and that is devoted to improve the transport and communication (TC) technology that firms adopt to reach the market.

Firms competing in quantities and producing homogeneous goods have an incentive to undertake TCRD if the advantage they get is fairly high, that is, if the e¢ciency boost associated with the resulting TC technology is large. This outcome is the result of a prisoner's dilemma situation where social welfare is maximised, while …rms do not maximise their aggregate payo¤.

For lower levels of e¢ciency, …rms shun TCRD investment, while the social planner would like them to undertake it. In such a case, it appears that a subsidy to TCRD could be introduced to obtain a second best result. As the e¢ciency of TCRD fades, the stance of …rms and social planner converge since investment in TCRD is undesirable both from a private and from a social standpoint.

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