Product and Process Innovation in a Differentiated Goods Duopoly

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Abstract

This paper compares Bertrand and Cournot equilibria in a differentiated duopoly with R&D competition or cooperation, where R&D may affect both unit cost of production and the size of the market. This combination of product and process innovation is shown to allow for the reversal of some results found in earlier models that only look at one of the two types of R&D effects. We find that for a sufficiently negative demand effect of R&D, the Bertrand equilibrium will give the highest R&D effort. Furthermore, expanding upon existing models, we illustrate how including demand effects of R&D and product differentiation, increases the scope for R&D to be larger when firms cooperate in their R&D. We also show how quantity competition in the product market is more likely to secure greater R&D levels under cooperation between the firms than price competition does, *ceteris paribus*.

JEL Classification: L13

Keywords: Product and process R&D, Price versus quantity competition

1. Introduction

Firms' research and development efforts fall broadly into two classes. R&D that is designed to reduce production costs compared to competitors is known as process innovation, whilst product innovation aims to change or create a demand for a product. The seminal work on the former by d'Aspremont and Jacquemin (1988) has lead to a burgeoning literature, and empirical studies also show both forward and backward linkages of R&D to customers and suppliers (Scherer, 1982, 1984). One common point of comparison for R&D models is how the type of product market competition affects the incentives to innovate. Qiu (1997) looks at the amount of resources used on process innovation depending on whether firms compete in prices or quantities in horizontally differentiated products, and Symeonidis (2003) does the same for product innovation where R&D affects the quality of a product and hence its demand (vertical differentiation). In both cases, an unambiguous conclusion is reached in which the amount of R&D is larger when firms are Cournot competitors in the product market. In this paper we consider R&D that may affect both the unit cost of production, and the size of the market. Taken in isolation, either of these effects yields the same conclusion as Qiu (1997) and Symeonidis (2003); we demonstrate, however, that process and product innovation in combination can reverse the results.

The type of R&D activity that we consider is one that is designed to reduce production costs, but that can spill over onto market demand, affecting its size[1]. One justification for this is due to increasing consumer awareness where firms have to take into account how their markets may react to R&D, for instance with regard to animal testing, environmental encroachments and recently in genetically modified organisms (GMOs). In these cases R&D may impart a negative effect on demand since this type of biotechnology has had an associated health concern (see, for example, the EU report "Plants for the Future", European Commission, 2004).[2] Growing genetically modified crops that reduce the need for insecticide for example changes both the structure of costs and may wee affect demand

[1] Lin and Saggi (2002) and Rosenkranz (2003) look at the case in which firms can undertake product and process innovation separately, or choose to combine them. Our focus is different, since we consider spillover effects from process innovation to product demand.
[2] That firms' business practices in general can affect demand has been demonstrated recently in Norway. The state-owned dairy (Tine) attempted to pay a retailer to remove its competitor's cheese products from its shelves; when this was disclosed, a consumer boycott of Tine's cheeses ensued causing its sales to fall by about 25% (Dagens Nærlingsliv ("ICA skandalen svir for Tine", 17.03.05 – in Norwegian).

negatively. On the other hand, intensive R&D in the production of high-tech consumer articles may impart a positive spillover on the market, even if this is not the original intention. A firm that is seen to be spending resources on R&D may gain a reputation for making reliable products for example. In a related context, Foros et al (2003) consider a model of the mobile telecommunications market in which firms may invest in infrastructure quality to increase demand, but the investment can be seen as affecting production costs also. The amount that this investment affects the demand faced by other firms depends upon a "roaming" parameter indicating the degree to which the new infrastructure may be shared. A rather different example is presented by Oehmke et al. (2005) who note that the aim of much of the agricultural biotechnology R&D industry is to develop higher quality inputs that can lower production costs for agricultural producers.[3] Recent innovations in e-commerce may also be considered as examples of innovation that affect both costs and demand, such as electronic tickets and internet banking.

A second issue that has been central in the R&D literature is the incentive that firms have to cooperate at the R&D stage. Following the lead of d'Aspremont and Jacquemin (1988), a vast amount of research has to a large degree confirmed the main conclusion that the incentive to cooperate on R&D investments is strengthened if technological spillovers between firms are large. Other research has indicated the effects on R&D cooperation of the number of competing firms, and the exact nature of cooperation.[4] De Bondt and Veugelers (1991) and Brod and Shivakumar (1997) consider R&D cooperation when firms produce differentiated products, and compete in quantities in the product market. De Bondt and Veugelers (1991) show that a lower technological R&D spillover is needed when substitute products are more differentiated in order to make a cooperative R&D strategy more advantageous than a non-cooperative one. When products are complements in demand, this effect is strengthened. We use the model in our paper to analyse the incentive to cooperate at the R&D stage, and how this depends upon the nature of competition in the product market, and the effect of R&D on process and product innovation.

The paper is organized as follows: the next section presents the basic framework of the model, whilst Section 3 presents the cases of quantity and price competition in the product

[3] That demand may be sensitive to regulation and/or friom strategy is also noted by Teisl et al (2002) who document how the imposition of eco-labelling, and specifically Dolphin-Safe labelling of canned tuna in the US, increased the market share of this product.
[4] For example, see Kamien et al. (1992) and Suzumura (1992).

market, and non-cooperation in the R&D market. Section 4 introduces cooperation in the R&D market for both quantity and price competition, and Section 5 sums up the findings.

2. The model

Two firms, 1 and 2, produce horizontally differentiated products and face demand:

(1) $$p_i = a - q_i - gq_j,\ i,j=1,2,\ i \neq j$$

where p_i is product price, q_i quantity and $g \in (0,1)$ measures the degree of differentiation in the competitors' products. As g approaches one the products become more homogeneous. The firms' marginal cost of production is given by

(2) $$k_i = K - \delta(x_i + \beta x_j)$$

for $i,j=1,2,\ i \neq j$, and where $K>0$ is a constant, x_i is the R&D effort of firm i and $\beta \in [0,1]$ is a spillover parameter. To be able to distinguish cases in which process innovation takes place, the parameter $\delta = \{0, 1\}$ is used; $\delta=1$ ($\delta=0$) means that R&D does (not) affect costs. For simplicity, the firms initially face an identical and constant marginal cost of production, K; however, this marginal cost can be affected by the level of R&D. The extent that cost-reducing R&D leaks from one firm to another is measured by the parameter β which is exogenously given.[5] In keeping with the work by amongst others d'Aspremont and Jacquemin (1988) we assume that the cost of R&D is quadratic: $c(x_i)=vx_i^2/2$.

In much of the literature on R&D, the only function that this activity fulfills is one of cost reduction. Here, however, we assume that R&D may have a demand shifting effect as discussed in the introduction.[6] We capture the demand-shifting effect through the a parameter in (1) in the following manner:

(3) $$a = A + \alpha(x_i + x_j)$$

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[5] Several papers have attempted to endogenize this parameter: for example Katsoulacos and Ulph (1998).

[6] Levin and Reiss (1988) introduce demand effects from R&D in a general model of monopolistic competition Their focus is somewhat different to the current paper, since they are interested in estimating the effect of R&D on market concentration and we fix the number of firms at the outset.

where $A>K$ is a constant and α measures the extent of any demand spillover from R&D activity. This parameter can be positive, indicating a positive effect on demand from R&D, or negative, indicating that demand is reduced as a consequence of firms' innovative activity, in this latter case opening for a trade-off between cost and demand reduction. Bounds for α are not fixed a priori but will arise from the conditions for the existence of equilibrium in this model. Note that R&D activity affects market size here, and we have assumed for simplicity that this is independent of which firm carries out the R&D. [7]

The timing of the game is as follows. At stage 1 the firms simultaneously choose a level of R&D, and at stage 2 they compete in the product market given the marginal costs and demands that arise after the R&D subgame. We shall consider quantity and price competition separately in the product market; in both cases we shall focus on a non-cooperative situation. In the R&D subgame it will be possible for the firms to cooperate or act non-cooperatively (denoted by cases *C* and *N*).

3. Competitive R&D

We begin by considering the case in which the firms compete at the R&D stage, and when competition in the product market is either in quantities or in prices.

3.1 Quantity competition in the product market

Given the realization of the parameters a and k_i from stage 1, firm i seeks to choose q_i to maximise:

(4) $$\pi_i = (a - q_i - gq_j)q_i - k_i q_i .$$

In the Nash-Cournot equilibrium this results in a quantity of

[7] We have also considered a specification that permits a strategic effect at this stage. Firms' R&D may have asymmetric effects on own demand and rival demand; the model quickly gets intractable, and we have chosen to present the current version as its yields stark conclusions. Symeonidis (2003) presents a model in which firms compete in quality and quantity, but in which costs of production are fixed.

(5) $$q_i = \frac{2(a-k_i)-g(a-k_j)}{(2+g)(2-g)} \equiv \eta + \mu x_i + \theta x_j$$

where

(6) $$\eta = \frac{(A-K)}{(2+g)} > 0$$
$$\mu = \frac{2(\alpha+\delta)-g(\alpha+\delta\beta)}{(2+g)(2-g)}$$
$$\theta = \frac{2(\alpha+\delta\beta)-g(\alpha+\delta)}{(2+g)(2-g)}$$

The corresponding profit in the product market equilibrium is $\pi_i^Q = (q_i)^2$, where the Q superscript indicates quantity competition in the product market.

Given the solution to the product market subgame, the payoff that firm *i* maximizes by its choice of R&D expenditure given the rival's choice is then:

(7) $$\Pi_i^Q(x_i,x_j) = (q_i(x_i,x_j))^2 - \frac{vx_i^2}{2}.$$

The first order condition for a maximum, defining the best response functions for each firm are given by:

(8) $$2q_i(x_i,x_j)\frac{\partial q_i(x_i,x_j)}{\partial x_i} = vx_i \Rightarrow x_i = \frac{2\mu(\eta+\theta x_j)}{v-2\mu^2}$$

for *i,j=1,2, i≠j*. The second order condition for a maximum make the denominator in (8) positive. Evaluating this expression at a symmetric situation gives the level of R&D effort per firm in the fully non-cooperative case as:[8]

(9) $$x^{NQ} = \frac{2\mu\eta}{v-2\mu(\mu+\theta)}.$$

[8] Superscript NQ refers to non-cooperative behaviour in the R&D subgame, and quantity competition in the product market.

From the first part of (8), we can see that in order for the first-order condition to be satisfied, we require that $\frac{\partial q_i\,(x_i,x_j)}{\partial x_i} \equiv \mu > 0$. In addition to this and the second order condition, a stability condition needs to be fulfilled that dictates that the denominator in (9) is positive.[9]

Given the second order condition, and the fact that μ>0, it is apparent that the slope of the best response function in (8) is dictated by the sign of θ which may be positive or negative. In the former case, the R&D efforts of the two firms are strategic complements, and in the latter strategic substitutes.

3.2 Price competition in the product market

When price is the strategic variable in the product market, the firms' optimal choice is given by:

$$p_i = \frac{a(2-g^2-g)+2k_i+gk_j}{(2+g)(2-g)} \equiv \omega + \phi x_i + \varphi x_j \tag{10}$$

where

$$\begin{aligned} \omega &= \frac{A(1-g)+K}{(2-g)} > 0 \\ \phi &= \frac{\alpha(2-g^2)-2\delta-g(\alpha+\delta\beta)}{(2+g)(2-g)} \\ \varphi &= \frac{\alpha(2-g^2)-2\delta\beta-g(\alpha+\delta)}{(2+g)(2-g)} \end{aligned} \tag{11}$$

Equilibrium profit from the product market subgame is given by

$$\pi_i^P(x_i,x_j) = \frac{(p_i(x_i,x_j)-k_i(x_i,x_j))^2}{1-g^2}$$

[9] On the stability condition in Cournot models in general see Seade (1980), and for its application in two stage R&D games see Henriques (1990) and Qiu (1997).

where the superscript *P* indicates price competition.

Behaving non-cooperatively at the R&D stage leads each firm to maximise $\Pi_i^P = \pi_i^P(x_i, x_j) - \frac{vx_i^2}{2}$ with respect to x_i, taking the R&D effort of the other firm as given. The first and second order conditions for an interior maximum are given by:

(12)
$$\frac{2(\phi+\delta)(\omega + x_i(\phi+\delta) + x_j(\varphi+\delta\beta) - K)}{1-g^2} - vx_i = 0$$
$$\frac{2(\phi+\delta)^2}{1-g^2} - v < 0$$

The parameter combination $\phi+\delta>0$ to ensure that the marginal effect of x_i on π_i^P is positive, otherwise no interior symmetric equilibrium will exist. Solving for the symmetric equilibrium gives an R&D effort per firm of[10]

(13)
$$x^{NP} = \frac{2(\phi+\delta)(\omega-K)}{v(1-g^2) - 2(\phi+\delta)(\phi+\delta+\varphi+\delta\beta)}$$

The stability condition ensures that the denominator in (13) is positive. Straightforward comparison of the expressions in (9) and (13) using the definitions given in (6) and (11) yields the following result:

Proposition 1: *Assume that the parameters are such that x^{NQ} and x^{NP} exist and are the equilibrium R&D levels from their respective games. Then $x^{NQ} > x^{NP}$ if $2\alpha > -\delta(1+\beta)$.*

The result in Proposition 1 encompasses and extends those of Qiu (1997) and Symeonidis (2003) who find that R&D is always larger when firms compete in quantities in the product market; Qiu (1997) considers the case of horizontally differentiated products in which R&D is cost-reducing, whilst Symeonidis (2003) looks at R&D as a means to vertically differentiate products through quality choice, and with constant costs. In the current model R&D can potentially have two effects that we can consider in isolation and in combination.

[10] Superscript NP refers to non-cooperative R&D subgame and price competition in the product market.

If there is no process innovation then δ=0, and the expressions for R&D levels in (9) and (13) can only be positive for α>0; hence $x^{NQ} > x^{NP}$ for this case. If there is no spillover of R&D on demand but there is process innovation (α=0, δ=1), then Propostion 1 immediately gives the same result: $x^{NQ} > x^{NP}$. Either of the two R&D effects in isolation gives the same result as Qiu (1997) and Symeonidis (2003). When the two effects are combined ($\alpha \neq 0$, δ=1) then it is actually possible that more R&D will arise if firms compete in prices in the product market, if the market reacts sufficiently negatively to the R&D.

To explain this, consider the effect that R&D has on equilibrium price and quantity in the two cases considered so far:

$$\begin{aligned} q^{NQ} &= \frac{A-K+(2\alpha+\delta(1+\beta))x^{NQ}}{2+g} \\ p^{NQ} &= \frac{A+(1+g)K+(2\alpha-(1+g)\delta(1+\beta))x^{NQ}}{2+g} \\ q^{NP} &= \frac{A-K+(2\alpha+\delta(1+\beta))x^{NP}}{(2-g)(1+g)} \\ p^{NP} &= \frac{A(1-g)+K+(2\alpha(1-g)-\delta(1+\beta))x^{NP}}{2-g} \end{aligned} \tag{14}$$

We see in each case that the condition $2\alpha > -\delta(1+\beta)$ secures that quantity is increasing in R&D in equilibrium, and that this must prevail if R&D just has the one effect. Cost-reducing R&D makes Cournot competitors behave more aggressively in the product market, shifting their reaction functions outwards. Bertrand competitors face an inwards shift of their reaction functions, reducing price, and hence have less incentive to undertake R&D activity. This is the usual intuition behind Qiu's result. If R&D has a twofold effect, reducing costs and affecting demand, it is possible for the inequality to be reversed so that equilibrium quantities are decreasing in firms' R&D if $2\alpha < -\delta(1+\beta)$. Consider now the incentives of Cournot competitors from a state of equilibrium. An extra unit of R&D by firm *i* will still shift its reaction function out, but the reaction of the competitor will be to move its reaction function so far in that total quantity will fall. Since each firm has the same incentives, this process will result in a large fall in quantity that hurts both firms. Hence the incentives to undertake R&D are dampened for Cournot competitors when the demand effect of R&D activity is sufficiently large and negative. For Bertrand competitors, and extra unit of R&D by firm *i* would still shift its reaction function inwards, but the response of the competitor is of a lower magnitude, and hence the change in the intensity of competition is less than in the Cournot case.

4. Cooperative R&D

4.1 Quantity competition

If the two firms can cooperate on their R&D activities but compete in quantities in the product market then they choose x_1 and x_2 to maximize:

(15) $$\Pi_1^Q(x_1,x_2)+\Pi_2^Q(x_1,x_2)=(q_1(x_1,x_2))^2+(q_2(x_1,x_2))^2-\frac{vx_1^2}{2}-\frac{vx_2^2}{2}$$

The optimal interior solution for each firm is given by:

(16) $$x^{CQ}=\frac{2\eta(\mu+\theta)}{v-2(\mu+\theta)^2}$$

given that the second-order condition is fulfilled: $v-2\mu^2-2\theta^2>0$.

The positive marginal contribution to profit of an extra unit of R&D is positive only if $\mu+\theta>0$. This implies that $2\alpha+\delta(1+\beta)>0$. Proposition 2 compares the R&D efforts in the non-cooperative and cooperative cases, given Cournot competition in the product market.

Proposition 2.

Assume that the model parameters are such that the cooperative and non-cooperative R&D equilibria both exist, and that the firms are Cournot competitors in the product market. Then sign $(x^{CQ}-x^{NQ})=sign(d\pi_i/dx_j)=sign\ \theta$, *i.e.*

i) if $\delta=0$ *then* $x^{CQ}>x^{NQ}$. *Furthermore,* $p^{CQ}>p^{NQ}$ *and* $q^{CQ}>q^{NQ}$

ii) if δ=1 then $x^{CQ} > x^{NQ}$ *and* $q^{CQ} > q^{NQ}$ *for* $\beta > \frac{g(1+\alpha)-2\alpha}{2} \equiv \beta^{Q}$. *If additionally*

$\frac{2\alpha}{1+g} > 1+\beta$ *then and* $p^{CQ} > p^{NQ}$.

<u>Proof</u>

That sign (x^{CQ}-x^{NQ}) = sign ($d\pi_i/dx_j$) is well known (see for example De Bondt and Veugelers,1991; equation 13). That sign ($d\pi_i/dx_j$) = sign θ follows from (4) and (5). Since the denominator of θ is positive, its sign depends just on the numerator. When δ=0, sign α = sign θ, and in this case α>0 for positive R&D giving i). Part ii) follows directly from the definition of θ when δ=1.

The results for the quantities follow from (5) noting that this variable is increasing in R&D since $\mu + \theta > 0$ when the cooperative solution exists. The results for price follow from (1) making the necessary substitutions in equilibrium from (3) and (5). In case (i), price is increasing in R&D if $\alpha > 0$ which must be the case for positive R&D if there is no cost reducing effect. The condition in (ii) suffices to ensure that price is increasing in R&D when this activity also reduces marginal cost of production.

QED

When R&D does not affect costs, the incentive to carry out this activity comes from the demand creating effect (i.e. α must be positive). Firms that compete at the R&D stage know that some of their own R&D will create demand for the rival's product, reducing the incentive to innovate. In a cooperative solution this externality is internalized leading to more R&D. This raises the product price and the quantity as compared to the non-cooperative equilibrium due to increased demand.

Suppose now that R&D does reduce costs so that part (ii) of Proposition 2 is valid. R&D is higher in the cooperative case if the technological spillover β is sufficiently large. Notice that when g=1 and α=0, we have the condition derived by d'Aspremont and Jacquemin (1988) of β>0.5. In our model, however, it is possible for R&D to be larger in the cooperative case for smaller technological leakages; this is the case when the demand spillover is not too negative and/or the products are less substitutable. Given quantity competition in the product market, the β^{Q} loci in Figure 1 delineate the area for which R&D

is larger in the cooperative case for different values of g; these loci pivot at the point α=-1, β=1 becoming flatter as g is increased.

The case considered by d'Aspremont and Jacquemin (1988) is $g=1$, $\alpha=0$, and the points in their model that give more R&D in the cooperative case are indicated by the heavy line in the figure. However, the figure also makes clear that scope for cooperation to increase total R&D is larger when product differentiation and demand spillovers are taken into account. With quantity competition, the more differentiated the final products, the more likely it is that R&D will be higher in the cooperative case, given values for the demand and the technological spillovers. The negative slope of the β^Q loci also indicates that the two types of spillover can substitute for each other in comparing R&D levels from the competitive and cooperative regimes. For example cooperation will be expected to give more R&D than competition even for low levels of β if α is sufficiently large.

Figure 1 about here

From Proposition 2, we can also see the effect that the cooperative R&D strategy has on quantity and price when R&D has a dual effect. Quantity is increasing in R&D as long as the cooperative solution exists, so that the regime that gives most R&D also ensures the largest traded quantity. Price is also increasing in R&D as long as the increase in demand (adjusted for product differentiation) is larger than the reduction in marginal cost from each unit of R&D. Notice that if demand reacts negatively to R&D then the product price will fall in response to an increase in R&D (i.e. the second condition in case (ii) in Proposition 2 fails).

4.2 Price competition

When the firms set prices non-cooperatively in the product market but cooperate at the R&D stage, then the resulting amount of R&D is given by x^{CP} where

(17) $$x^{CP} = \frac{2(\phi+\delta+\varphi+\delta\beta)(\omega-K)}{v(1-g^2)-2(\phi+\delta+\varphi+\delta\beta)^2}$$

The marginal contribution to profit from an extra unit of R&D must be positive, and this is ensured by $\phi + \varphi > 0$. Proposition 3 gives results for the relative comparison between the cooperative and non-cooperative R&D level for the case of price-setting in the product market.

Proposition 3: *Assume that the parameters are such that x^{CP} and x^{NP} exist and are the equilibrium R&D levels from their respective games. Then $sign(x^{CP}-x^{NP})=sign(d\pi^P_i/dx_j)=sign(\varphi+\delta\beta)$, i.e. $x^{CP} > x^{NP}$ if i) $\delta=0$ or ii) $\delta=1$ and $\beta > \frac{g(1+\alpha)-\alpha(2-g^2)}{(2-g^2)} \equiv \beta^P$. In both of these cases $q^{CP} > q^{NP}$ and $p^{CP} > p^{NP}$*

<u>Proof:</u> The comparison of R&D levels is straightforward and omitted. To verify that price is increasing in R&D in equilibrium for this case requires simple inspection of (10) at the symmetric situation, recalling that $\phi + \varphi > 0$. For the results on quantity, note that in equilibrium for cases NP and CP: $q = \frac{A + 2\alpha x - (\omega + (\phi + \varphi)x)}{1+g}$ where we have used (1) and (10). Hence quantity is increasing in R&D if $2\alpha - (\phi + \varphi) > 0$. Inserting from (11) and rearranging gives this condition as $2\alpha + \delta(1+\beta) > 0$ which is a prerequisite for the cooperative solution to exist.

When the only effect of R&D is on demand, then this effect must be positive to be commensurate with equilibrium. For the same reason as with quantity competition, cooperative R&D will be higher in this case. When both types of spillover are present then cooperation gives more R&D for sufficiently large technical spillovers. Given price competition in the product market, the locus marked β^P in Figure 1 gives combinations of α and β that yield equal amounts of R&D in the two regimes for $g = \overline{g}$. Above this line, the cooperative regime results in more R&D. Note that $\beta^P(g)>\beta^Q(g)$ so that cooperation is more likely to result in more R&D when there is quantity competition in the product market, for a given set of parameters.

Proposition 4 compares the amount of R&D in the cooperative case, given the type of competition that exists in the product market.

Proposition 4: *Assume that the parameters are such that* x^{CQ} *and* x^{CP} *exist and are the equilibrium R&D levels from their respective games. Then* $x^{CQ} > x^{CP}$.

Proof

Comparing the R&D expressions shows that $x^{CQ} > x^{CP}$ if $2\alpha + \delta(1+\beta) > 0$ which must be the case for the cooperative solutions to exist.

5. Conclusion

Firms engage in process and product R&D with the goal of reducing costs and enhancing demand. The effects of these isolated processes have been documented in the literature. In this work, we consider the possibility that R&D that is designed to reduce costs may also affect public perception of a product, affecting its demand. When demand is enhanced then the results from the literature go through. However, if a change in process leads to a sufficiently large negative effect on product demand, this may reverse results found in the literature relating to the relative amounts of R&D in Cournot and Bertrand market structures. Negative market effects of R&D are increasingly becoming an issue as consumers become more sensitive to animal testing, genetic engineering and environmental effects. We demonstrate that for a sufficiently negative demand effect of R&D, firms that compete in price in the product market will have a higher R&D effort than a market where firms compete in quantity, reversing the results for solely one of the innovation types.

Furthermore, we illustrate how there is greater scope for R&D to be larger in the case of cooperative R&D behaviour, even with lower technological leakages than described by d'Aspremont and Jacquemin (1988); this is due to the demand effects of R&D and product differentiation. Hence expanding the model to include these issues increases the arena for cooperative R&D securing greater R&D efforts than non-cooperative behaviour. It is also shown how quantity competition in the product market is more likely to secure greater R&D levels under R&D cooperation between the firms than price competition does, *ceteris paribus*. Since R&D has several effects in the model, the welfare consequences of this activity are not possible to pin down analytically, and we have hence omitted this from the analysis.

References

Brod, A. and R. Shivakumar 1997. R&D cooperation and the joint exploitation of R&D. *Canadian Journal of Economics* 30(3) 673-684.

d'Aspremont, C. and A. Jacquemin 1988. Cooperative and non-cooperative R&D in duopoly with spillovers. *American Economic Review* 78(5) 1133-1137.

De Bondt, R. and R. Veugelers 1991. Strategic investment with spillovers. *European Journal of Political Economy* 7, 345-66.

European Commission, 2004. Plants for the future – 2025 a European vision for plant genomics and biotechnology, EUR 21359, Luxembourg.

Foros, Ø., B. Hansen and J. Y. Sand, 2003. Demand-side spillovers and semi-collusion in the mobile communications market. *Journal of Industry, Competition and Trade* 2(3) 259-278.

Henriques, I. 1990. Cooperative and non-cooperative R&D in duopoly with spillovers comment. *American Economic Review* 80, 638-40.

Kamien, M.I., E. Muller and I. Zang 1992. Research Joint Ventures and R&D cartels. *American Economic Review* 82(5) 1293-1306.

Katsoulacos, Y. and D. Ulph 1998. Endogenous spillovers and the performance of research joint ventures. *The Journal of Industrial Economics* 3, 333-57.

Levin, R.C. and P.C. Reiss 1988. Cost-reducing and demand-creating R&D with spillovers. *RAND Journal of Economics* 19(4) 538-556.

Lin, P. and K. Saggi 2002. Product differentiation, process R&D, and the nature of market competition. *European Economic Review* 46, 201-211.

Oehmke, J.F., C.A. Wolf, and K.C. Raper, 2005. On cyclical industry evolution in agricultural biotechnology R&D, *Journal of Agricultural & Food Industrial Organization*, 3, Article 1.

Qiu, L.D. 1997. On the dynamic efficiency of Bertrand and Cournot Equilibria. *Journal of Economic Theory* 75, 213-229.

Rosenkranz, S. 2003. Simultaneous choice of process and product innovation when consumers have a preference for product variety. *Journal of Economic Behavior and Organization* 50, 183-201.

Seade, J. 1980, The Stability of Cournot Revisited. *Journal of Economic Theory* 23(1) 15-27.

Scherer, F.M. 1982. Interindustry technology flows and productivity growth. *Review of Economics and Statistics* 64 627-34.

Scherer, F.M. 1984. Using linked patent and R&D data to measure interdindustry technolgy flows. In (Z. Griliches, ed.) *R&D, patents and productivity*. 417-64. Chicago: University of Chicago Press.

Suzumura, K. 1992. Cooperative and Noncooperative R&D in an oligopoly with spillovers. *American Economic Review* 82(5) 1307-1320.

Symeonidis, G. 2003. Comparing Cournot and Bertrand equilibria in a differentiated duopoly with product R&D. *International Journal of Industrial Organization* 21, 39-55.

Teisl, M.F , B. Roe and R.L. Hicks. 2002. Can Eco-labels Tune a Market? Evidence from Dolphin-Safe Labeling. *Journal of Environmental Economics and Management* 43 339-359

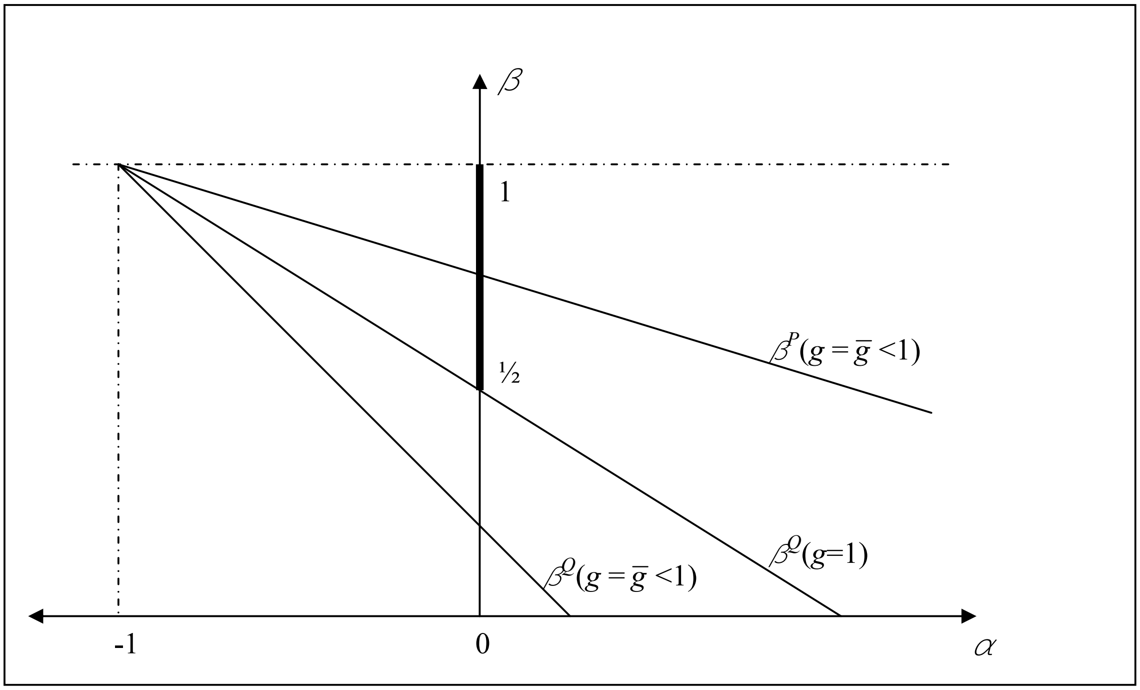

Figure 1

The area above the β-loci give the combinations of β (technological spillover) and α (demand shifting) that ensure larger R&D under cooperative R&D behaviour than non-cooperative behaviour. Increased product differentiation (g<1) increases this area both for competition in quantity (β^Q) and prices (β^P).