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Cournot Competition and "Green" Innovation: An Inverted-U Relationship

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Cournot Competition and "Green" Innovation: An Inverted-U Relationship*

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Comments most welcome

Abstract

We evaluate the relationship between competition and innovation in an industry where production is polluting and R&D has the aim to reduce emissions. We build up an oligopoly model where n firms compete in quantities and decide their investment in green R&D. When environmental taxation is exogenous, the investment in green R&D always increases with the number of firms in the industry. We analyse

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next the case where taxation is endougenously determined by a regulator with the aim to maximise social welfare. An inverted-U relationship exists under reasonable conditions, and it is driven by the presence of spillovers.
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1 Introduction

The link between competition and innovation has long been debated among economists. Theories of industrial organisation usually predict that innovation should decline with competition (Schumpeter, 1942). There are several arguments supporting the view that possession of market power should result in greater innovative activities. First, market power may be extendable to new products, for example, through a dominant firm's command over channels of distribution, and so on. With the ability to extend market power to new products, a current monopolist should find innovation more attractive. Second, there may be a need to finance innovation internally, which puts firms with market power at an advantage since these firms may have supernormal profits. Third, firms with current market power tipically have more resources and thus more likely to hire the most innovative people. Of course the third argument is related to the imperfect capital market argument underlying the second reason.

However, theoretical research also indicates that a monopolist can have less incentive to innovate. Arrow (1962) shows that a competitor can profit more than a monopolist from innovation, and the monopolist may be slower in replacing it with a superior product or process than a newcomer. This is because the firm realising monopoly profits on its current product calculates the profit from innovation as the difference between its current profits and the profits it could realise from the new product, whereas the competitor regards the profits from the new product as the gain. As such, the larger current monopoly profits are, the less incentive the monopolist has to innovate. Moreover, a monopolist may regard additional leisure as superior to additional profits. This may be due to the lack of active competitive forces and thus generates an x-inefficiency effect.

The lively debate on the relationship between competition and innnovation is still open both in the theoretical and empirical literature. Theoretical models comparing a monopolist and an entrant incentives to innovate also provide mixed predictions about the impact of monopoly power on innovative effort. Factors such as uncertainty in the innovation process and the strategic relation between new and existing products may motivate entrants to spend more on R&D relative to incumbents.[1] The early empirical literature showed no clear-cut results in the relationship between market structure and innovative activity.[2] Subsequently, a large evidence showing an increase of innovation with competition has been found.[3] According to these results, technological opportunity is what largely determines innovative activity and must be controlled for when investigating the relationship between market structure and innovation.[4]

In a recent contribution, Aghion *et al.* (2005) provide evidence of an inverted-U relationship. Their theoretical explanation is based on Aghion *et al.* (1997). This is a neo-Schumpeterian growth model, in which both technological leaders and followers in any industry can innovate, and innovations all occur step-by-step. Innovation incentives depend upon the difference between postinnovation and preinnovation rents of incumbent firms. In this case, more competition may foster innovation and growth, because it may reduce a firm's preinnovation rents by more than it reduces its post-innovation rents. One aspect that has not been considered is the relationship between competition and innovation in a polluting industry where R&D investment has the aim to reduce the environmental impact of production.

[1] See Gilbert and Newbery (1982), Reinganum(1983), Chen (2000), and Gayle (2002), *inter alia*.

[2] See Kamien and Schwartz (1982) for a discussion.

[3] See Levin *et al.* (1985), Cohen *et al.* (1987), Cohen and Levin (1989), Geroski (1990), Blundell *et al.*, (1995, 1999), *inter alia*. In a recent study on market concentration and innovation in Central and Eastern Europe, Voinea (2008) shows that competition enhances knowledge creation.

[4] Some empirical work consider the possibility that R&D intensity and market structure are both determined by other market characteristics. Levin & Reiss (1984, 1988): analyse R&D and concentration in simultaneous equations models controlling for technical opportunity and appropriability conditions. According to Symeonidis (1996), R&D intensity and market structure are jointly determined by technology, the characteristics of demand, the institutional framework, strategic interaction and chance.

In this paper we verify the presence of an inverted-U relationship between competition and innovation in a microeconomic setting of oligopolistic competition where production is polluting and innovation has the aim of reducing emissions. Given the presence of Pigouvian taxation, reducing pollution would lead to decrease production costs.[5] We build up an oligopoly model where firms compete in quantities and decide their investment in green R&D, and spillovers are present in the industry. We establish the link between competition and green innovation through the variation of total investment in R&D according to the number of firms in the industry. We consider three different scenarios. First, we assume that taxation is exogenously established. In this case our results present a strong Arrowian flavour, i.e., the investment in R&D monotonically increases with the number of firms. We consider next the presence of an environmental regulator that sets the optimal taxation on pollution. We examine both cases in which the regulator can and cannot commit credibly to the taxation policy (Petrakis and Xepapadeas, 2001 and 2003, and Golombek *et al.*,2010). With endogenous taxation we find that the relationship between competition and green R&D is represented by an inverted U. We show that this result is driven by the presence of spillovers and we establish the necessary conditions. The results obtained by Aghion *et al.* (2005) are thus confirmed in a microeconomic framework where innovation has the aim of abate polluting emissions.

The paper is related to the literature of innovation and market structure. Hausman (1988) argued that the actions of monopolies with regards to third-degree price discrimination, may lead to social welfare improvement due to opening new markets, achieving economies of scale and higher efficiency and, importantly, increasing net social welfare. Geroski and Pomroy (1990) show that innovating may be a way to obtain market power, in particular they find that innovation increases the degree of competition in markets. This leads to

[5] The introduction of Pigouvian taxation by a regulator also dates back to Keeler *et al.* (1971), and has been largely examined in the literature.

a fall in market concentration over time and eventually to the emergence of very few and large firms. Therefore firms innovate with the aim to become incumbents. Etro (2004) shows that the innovative process is naturally connected to the persistence of monopolies. Their investment in research and development would be beneficial to society as they advance new technologies. Our paper contributes to this strand by focussing on innovation with "green" features.

The paper is also related to the literature on organisational structure of environmental R&D, cooperative versus independent pollution abatement (Scott, 1996, Chiou and Hu, 2001, Petrakis and Poyago-Theotoky, 2002, Sandonís and Mariel, 2004, Poyago-Theotoky, 2007, and Golombek and Hoel, 2008, *inter alia*). With this literature, we share the assumption of R&D efforts being not directed towards process or product enhancement, but directed towards emission reduction of harmful pollutants. The analysis in the paper is close to Poyago-Theotoky (2007), who examines the issue of green R&D cooperation vs competition in a polluting industry where two firms operate and endogenous taxation set by a pre-commited regulator. Compared to Poyago-Theotoky (2007), we set aside the R&D cooperation issue, we consider an oligopoly rather than a duopoly, and we also analyse the case in which the regulating policy is time-consistent.

The remainder of the paper is organised as follows. Section 2 presents the model. Section 3 shows the results. Section 4 concludes.

2 The model

We study a static oligopoly market with $n > 2$ profit-maximising firms competing *à la* Cournot-Nash. Firms supply a homogeneous good, whose market demand function is $p = a - Q$, a being a positive constant parameter measuring the reservation price and $Q = \sum_{i=1}^{n} q_i$ being the sum of all firms' individual output levels q_i. Production generates pollution, which is taxed at the emission tax rate t, while firm i can reduce its tax burden by undertaking environmental R&D, z_i, to reduce its emissions. The cost function for firm i is given by $c(q_i, z_i) = cq_i + \gamma z_i^2/2$, where c is the unit cost of production, $a > c$, and $\gamma > 0$ is a parameter measuring the cost of investing in R&D. The firm's i emissions are

$$e_i(q_i, z_i) = q_i - z_i - \beta \sum_{j \neq i}^{n} z_j > 0,$$

where $\beta \in (0, 1)$ represents R&D spillovers. We denote the total amount of R&D as $Z = \sum_{i=1}^{n} z_i$ and the total investment in R&D as $\gamma Z^2/2$. Hence firm i's profit function is $\pi_i = pq_i - c(q_i, z_i) - te_i(q_i, z_i)$, so that taxation is a linear function of emissions. Total emissions are $E = \sum_{i=1}^{n} e_i(q_i, z_i)$, and the damage function is a quadratic function of emissions, $D = dE^2$, where d represents the marginal damage of emissions. To guarantee an interior solution for R&D, in what follows we will assume $d > (1/n)$ (Poyago-Theotoky 2007, Petrakis and Xepapadeas, 2001 and 2003).

This implies that environmental damages are not insignificant for the economy. Finally, total tax revenue is $T = t\sum_{i=1}^{n} e_i$, whereas consumer surplus is measured by $CS = Q^2/2$. Social welfare is defined as the sum of industry profits and consumer surplus, plus tax revenue, minus the environmental damage:

$$W = \sum_{i=1}^{n} \pi_i + \frac{Q^2}{2} + T - dE^2. \tag{1}$$

For notational simplicity we shall define market size as $m = a - c$.

We separately consider three different cases. In the first case, taxation is exogenously given. In this scenario, there is a two-stage game in which firms non-cooperatively choose their investment in green R&D in the first stage and compete in the second stage. We then assume taxation being endogenously determined by a regulator with the aim of maximising social welfare. In particular, in the second case we suppose that the regulator pre-commits to its environmental policy. In other words, the optimal taxation does not react to the firms' decisions on R&D investment, but it is predetermined. The game is now a three-stage game where, in Stage 1, the regulator sets the environmental tax so as to maximise social welfare, in Stage 2, firms invest in green R&D and in stage 3 market competition occurs. In the last case environmental regulation is time-consistent. This implies that the optimal taxation is able to adapt to the level of investment in R&D. As a consequence, the R&D investment takes place in Stage 1 and the welfare-maximising taxation in Stage 2. The equilibrium concept is perfect subgame equilibrium with backward induction.

3 Results

Begin the analysis by examining market competition. This stage do not change along the cases considered. Firm i chooses output to maximise profits. The market equilibrium is given by:

$$q_i^* = \frac{m-t}{1+n}.$$

Notice that the equilibrium quantity does not depend on abatement directly, but it is affected by it through taxation. The equilibrium profit is:

$$\pi_i^* = \frac{2\left(m-t\right)^2 + \left(1+n\right)^2 \left[2t\left(z_i + \beta \sum_{j \neq i}^{n} z_j\right) - \gamma z_i^2\right]}{2\left(1+n\right)^2},$$

and is the same in each configuration considered below.

3.1 Exogenous taxation

Consider first the case with exogenous taxation, where, in the first stage, firm i chooses R&D investment. The amount of R&D in equilibrium is equal to the unitary tax, $z_i^* = t/\gamma$. Thus total R&D is:

$$Z_1^* = \frac{nt}{\gamma},$$

where the subscript 1 represents the case considered. Clearly, total R&D monotonically increases with the increase of firms in the market. Thus with exogenous taxation we obtain a clear-cut Arrowian result.

Proposition 1 *With exogenous taxation, there is a positive relationship between competition and green R&D.*

3.2 Pre-committed policy

Consider next the cases with endogenous taxation. In the second configuration, the regulator pre-commits to its environmental policy. Compared to the case with exogenous taxation, now there is a stage before the R&D investment in which the regulator sets taxation so as to maximise social welfare. The equilibrium rate t is:

$$t_2^* = \frac{m\gamma\left[2dn\left(n+1+\gamma+\beta\left(n^2-1\right)\right)-\gamma\right]}{n\gamma^2\left(1+2d\right)+\gamma\left(1+n\right)\left[1+n\left(1+4d\left(1+\beta\left(n-1\right)\right)\right)\right]+2dn\left[n+1+\beta\left(n^2-1\right)\right]^2}.$$

Total R&D is:

$$Z_2^* = \frac{m\left[2dn\left(n+1+\gamma+\beta\left(n^2-1\right)\right)-\gamma\right]}{\gamma^2\left(1+2d\right)+\gamma\left(1+n\right)\left[1+n\left(1+4d\left(1+\beta\left(n-1\right)\right)\right)\right]+2dn\left[n+1+\beta\left(n^2-1\right)\right]^2}.$$

A sufficient condition for Z_2^* to be non-negative is $d > (1/2n)$. In order to obtain a fully analytical results, we evaluate the shape of the total R&D function: if Z_2^* is a continuous function on n, the first derivative is positive for a small number of firms, say $n = 1$, and the limit of the function when n tends to infinity is zero, then for the Rolle and Lagrange's theorems the total R&D function entails an inverted-U shape. The first derivative of Z_2^*

with respect to n when $n = 1$ is:

$$\left.\frac{\partial Z_2^*}{\partial n}\right|_{n=1} = \frac{2dm\left[2d\left(1+\gamma-2\beta\right)\left(2+\gamma\right)^2+\gamma\left(16+\gamma\left(9+\gamma\right)+2\beta\left(8+3\gamma\right)\right)\right]}{\left[2d\left(2+\gamma\right)^2+\gamma\left(4+\gamma\right)\right]^2} \tag{2}$$

The sufficient condition under which (2) is positive is

$$\gamma > \widetilde{\gamma} \equiv 2\beta - 1.$$

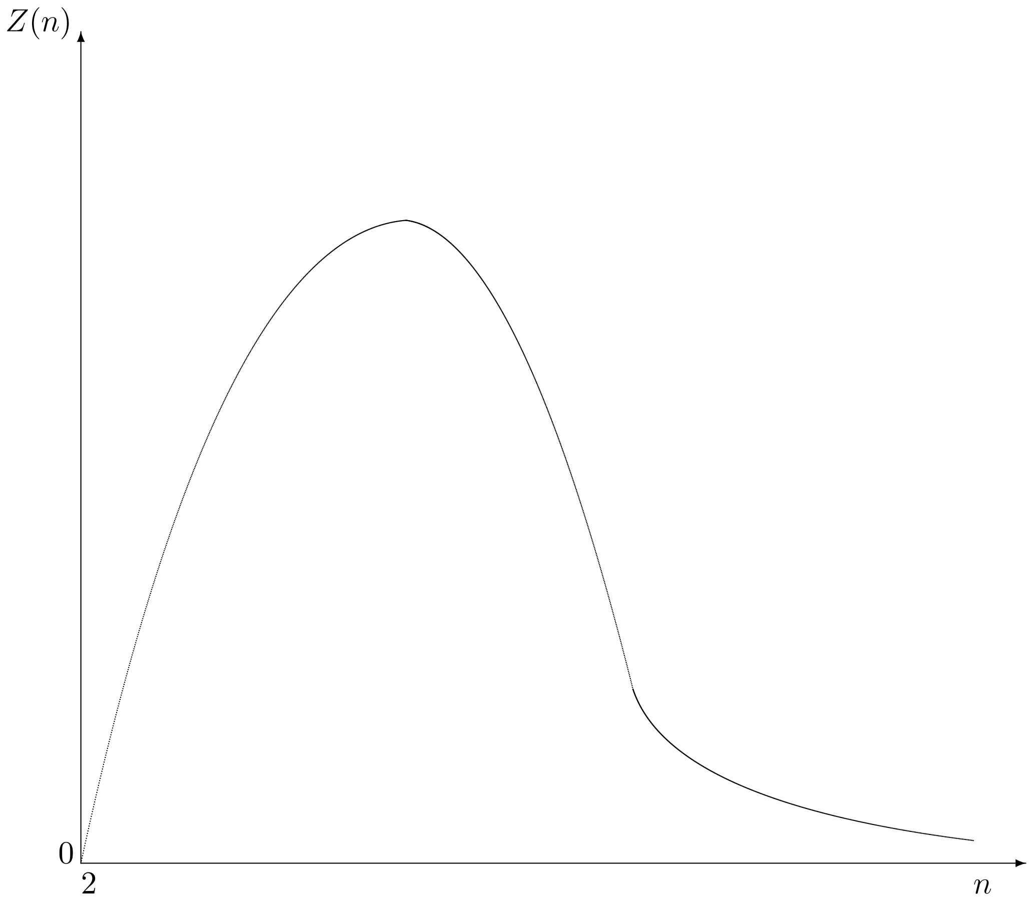
Consider next the limit of Z_2^* and $\partial Z_2^*/\partial n$ when n tends to infinity:

$$\lim_{n\to+\infty} Z_2^* = 0, \ \lim_{n\to+\infty} \frac{\partial Z_2^*}{\partial n} = 0$$

This result shows that the total R&D function with respect to the number of firms in the industry features an inverted U, and can be summarised as follows.

Proposition 2 *Consider endogenous taxation and pre-committed policy. Suppose $\gamma > \widetilde{\gamma}$. Then the total R&D presents the shape of an inverted U with respect to the number of firms (Figure 1).*

Figure 1. An inverted-U relationship



In order to highlight the role of spillovers, consider finally the case with no spillovers, $\beta = 0$. Total investment in R&D is

$$Z_2^*|_{\beta=0} = \frac{m\left[2dn\left(n+1+\gamma\right)-\gamma\right]}{\gamma^2\left(1+2d\right)+\gamma\left(1+n\right)\left[1+n\left(1+4d\right)\right]+2dn\left(n+1\right)^2},$$

and the first derivative of $Z_2^*|_{\beta=0}$ with respect to n is:

$$\begin{aligned}\left.\frac{\partial Z_2^*}{\partial n}\right|_{\beta=0} &\propto 4d\gamma n(1+\gamma)+n^2\left[4d^2(1+\gamma)^3+2d\gamma(7+\gamma(5+\gamma))\right]+\\ &+4dn^3\left[2d(1+\gamma)^2+\gamma(3+\gamma)\right]+\\ &2dn^4\left[\gamma+2d(1+\gamma)\right]+\gamma^2n^2-\gamma^2\\ &> 0,\end{aligned}$$

which exhibits a clear-cut Arrowian result.

Corollary 1 *Consider endogenous taxation, pre-committed policy and no spillovers. Then there is a positive relationship between competition and green R&D.*

Corollary 1 proves that the inverted-U effect is driven by the presence of spillovers. It also provides an intuition for the result depicted in Proposition 1, since an exogenous tax does not transfer the effect of spillovers in the R&D schedule.

3.3 Time-consistent policy

Consider next the case in which the regulator is able to adopt a time consistent environmental policy. In this case, the welfare-maximising tax rate is determined in the second stage:

$$t_3^* = \frac{m(2dn+1)-d\sum_{i=1}^n z_i(n+1)\left[1+\beta(n-1)\right]}{n(1+2d)}.$$

In the first stage firm i chooses R&D investment. The amount of R&D in equilibrium is:

$$Z_3^* = \frac{m\left[2d\left(2+2\beta(n-1)+n(n+2dn-1)\right)-n\right]}{\gamma n+2d\left(1+\beta^2(1+n)(n-1)^2+\beta(1+n)(2+n)(n-1)+n(2+2\gamma+n)\right)+}$$

$$\overline{4d^2\left(\beta^2(n-1)^3-1+n(n+2+\gamma)+\beta(n-1)(n(3+n)-2)\right)}.$$

We then verify the relationship between competition and innovation by following the same procedure as in the pre-committed case. The first derivative of Z_3^* with respect to n when $n=1$ is:

$$\left.\frac{\partial Z_3^*}{\partial n}\right|_{n=1} = \frac{[2d(1+2\beta+4d)-1][\gamma+4d^2(2+\gamma)+2d(4+2\gamma)]}{[\gamma+4d^2(2+\gamma)+2d(4+2\gamma)]^2} - \tag{3}$$

$$\frac{[2d(2+2d)-1][\gamma+2d(\beta(6+4d)+2(2+\gamma+d(4+\gamma)))]}{[\gamma+4d^2(2+\gamma)+2d(4+2\gamma)]^2}.$$

Since the denominator is positive, we focus on the sign of the numerator of (3). By collecting γ and rearranging:

$$\left.\frac{\partial Z_3^*}{\partial n}\right|_{n=1} \propto \gamma(1+2d)^2 2d(2\beta+2d-1) - 4d\left[2d(1+2d)+\beta\left(2d\left(1+6d+4d^2\right)-3\right)\right].$$

This is positive for

$$\gamma > \widehat{\gamma} \equiv \frac{4d(1+2d)+2\beta[2d(1+6d+4d^2)-3]}{(1+2d)^2(2\beta+2d-1)} > 0,$$

for all $d > 1/n = 1$, $\beta \in (0,1)$.

Consider next the limit of Z_3^* and $\partial Z_3^*/\partial n$ when n tends to infinity:

$$\lim_{n\to+\infty} Z_3^* = 0, \ \lim_{n\to+\infty}\frac{\partial Z_3^*}{\partial n} = 0$$

The foregoing discussion can be summarised as follows.

Proposition 3 *Consider endogenous taxation and time-consistent policy. Suppose $\gamma > \widehat{\gamma}$. Then the total R&D presents the shape of an inverted U with respect to the number of firms.*

We can also compare the levels of γ in pre-committed and time consistent regime being necessary to trigger the inverted U bteween competition and green innovation. The difference between $\widehat{\gamma}$ and $\widetilde{\gamma}$ yields:

$$\widehat{\gamma}-\widetilde{\gamma}\propto(1+2d)\left[4d\,(1+d)-4\beta^2\,(1+2d)\right]+2\beta\,[4d\,(2+3d)-1]>0,$$

for all $d>1/n=1$, $\beta\in(0,1)$. Therefore,

Corollary 2 *The inverted U between competition and green innovation emerges for lower levels of the cost of R&D in the pre-committed regime.*

As previously, we then consider the case with $\beta=0$. In the time-consistent case, total investment in R&D is

$$Z_3^*|_{\beta=0}=\frac{m\,[2d\,(2+n\,(n+2dn-1))-n]}{\gamma n+2d\,(1+n\,(2+2\gamma+n))+4d^2\,(n\,(n+2+\gamma)-1)},$$

and the first derivative of $Z_3^*|_{\beta=0}$ with respect to n is:

$$\begin{aligned}\left.\frac{\partial Z_3^*}{\partial n}\right|_{\beta=0} &= \left(n^2-1\right)(1+6d)+2d\gamma n^2+2\gamma\left(dn^2-1\right)(1-2d)+4dn\,(2dn-2d-1)\\ &> 0.\end{aligned}$$

Even with time-consistent policy, the inverted-U effect is driven by the presence of spillovers.

Corollary 3 *Consider endogenous taxation, time consistent policy and no spillovers. Then there is a positive relationship between competition and green R&D.*

4 Concluding remarks

We have analysed the relationship between competition and innovation when R&D investment has the aim of reducing polluting emissions. The problem is tackled from a microeconomic angle, through the analysis of an oligopoly where n firms compete *à la* Cournot and decide their investment in green R&D. In the case in which environmental taxation is exogenous, we show a clear-cut Arrowian result, according to which green innovation always increases with the number of firms in the industry. With endogenous taxation, we show that an inverted-U relationship emerges and is driven by the presence of spillovers, both in the pre-committed and time-consistent case.

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