Cournot competition and "green" innovation: An inverted-U relationship

Luca Lambertini, Joanna Poyago-Theotoky, Alessandro Tampierid

Energy Economics 68 (2017) 116-123

Presented by Yazeed Aldhafian

October 28, 2021

Literature

The paper is related to the literature on organizational structure of environmental R&D

- **Scott, 1996; Chiou and Hu, 2001; Petrakis and Poyago-Theotoky, 2002; Sandonís and Mariel, 2004; Poyago-Theotoky, 2007; Golombek and Hoel, 2008:**

We share the assumption of R&D efforts being directed not towards process or product enhancement but directed towards emission reduction of harmful pollutants.

- **Poyago-Theotoky (2007):**

Who examines the issue of R&D cooperation versus competition in a polluting industry where two firms operate and endogenous taxation is set by a time-consistent regulator. Compared to it, we set aside the R&D cooperation issue; instead, we consider an oligopoly rather than a duopoly, and we focus on the case in which the regulator is able to commit credibly to the setting of the environmental policy instrument. Finally, we assume that abatement is of the end-of-pipe variant.

Cont. Literature

The paper is related to the literature of innovation and market structure.

- **Hausman and MacKie-Mason (1988):**

Argued that the actions of monopolies with regard 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 (1990):**

Shows that innovating may be a way to obtain market power, in particular he finds that innovation increases the degree of competition in markets. This leads to 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 focusing on innovation with "green" features.

Research Questions

They examine the relationship between competition and innovation in an industry where production is polluting, and R&D has the aim to reduce emissions ("green" innovation).

The Model

- Consider a Cournot oligopoly model with n identical profit maximizing firms competing in quantities and supply homogeneous goods.
- Every firm i faces the inverse demand curve

$$p = a - Q; \text{ where } Q = \sum_{i=1}^{n} q_i ,$$

- Cost function for each firm i is $c(q_i, z_i) = cq_i + \frac{\gamma z_i^2}{2}$, where q_i denotes output level, $a >$ c,and $\gamma > 0$ is a parameter capturing the efficiency of the R&D technology.
- Pollution is taxed at the emission tax rate τ.
- Firm's i (net) emissions are:

$$e_i(q_i, z_i, Z_{\_i}) = q_i - z_i - \beta Z_{-i} \geq 0, \qquad where\ Z_{-i} = \sum_{j \neq i}^{n} z_j$$

- Firm i's profit is

$$\pi_i = pq_i - c(q_i, z_i) - \tau e_i(q_i, z_i)$$

- Total emissions are:

$$E = \sum_{i=1}^{n} e_i(q_i, z_i)$$

- The damage function is:

$$D = dE^2,$$ where d capturing the steepness of marginal

- To guarantee interior solutions in what follows they assume $d > \frac{1}{2n}$.

Cont. The Model

We examine a Three-Stages Game:

- Stage One, the regulator sets the emission tax to maximize social welfare.
- Stage Two, firms invest in “green” R&D.
- Stage Three market competition occurs.

Solving The Model

- In the last stage:

The market competition stage, firm I chooses output to maximize profit:

$$\max_{qi}\ (a - q_i - q_{\_i})q_i c q_i - \frac{1}{2}\gamma z_i^2 - \tau(q_i - z_i - \beta Z_{\_i})$$

F.O.C and imposing symmetry

$$q(\tau) = \frac{m-\tau}{1+n}, \qquad where\ m \equiv a - c$$

Notice that the equilibrium output does not depend on abatement directly, but it is affected by it through taxation.

$$\pi_i(z_i, \tau) = q(\tau)^2 + \tau\left(z_i + \beta \sum_{j \neq i}^{n} z_j\right) - \frac{1}{2}\gamma z_i^2$$

Cont. Solving the model

- In the second stage:

Firm “green” R&D (abatement effort) to maximize profit:

$$\max_{z_i} q(\tau)^2 + \tau\left(z_i + \beta\sum_{j\neq i}^{n} z_j\right) - \frac{1}{2}\gamma z_i^2$$

F.O.C and imposing symmetry

$$z(\tau) = \frac{\tau}{\gamma}, \qquad and \;\; Z(\tau) = \frac{n\tau}{\gamma}$$

Firms respond to an increase in the emission tax by increasing their “green” R&D. With no emission tax, then no ‘green” R&D.

Cont. Solving the model

- In the first stage:

The regulator sets the emission tax so as to maximize social welfare:

$$W = \int_0^{nq} (a - c - x)dx - \frac{1}{2}\gamma n z(\tau)^2 - \frac{1}{2} d n^2 [q(\tau) - (1 - \beta + \beta n) z(\tau)]^2$$

$$W = mnq(\tau) - \frac{1}{2}\left(nq(\tau)\right)^2 - \frac{1}{2}\gamma n z(\tau)^2 - \frac{1}{2} d n^2 [q(\tau) - (1 - \beta + \beta n) z(\tau)]^2$$

$$\max_{t} \quad n\left[m\left(\frac{m-\tau}{1+n}\right) - \frac{1}{2}\left(\frac{m-\tau}{1+n}\right)^2 - \frac{1}{2} dn \left[\frac{\gamma(m-\tau)-\tau(1-\beta+\beta n)}{2\gamma^2(n+1)^2}\right]^2 - \frac{\tau^2}{2\gamma}\right]$$

F.O.C

$$\tau^*(n) = \frac{n\gamma\left[\left(2d-\frac{1}{n}\right)\gamma+2d(1+n)(1+\beta(n-1))\right]}{F} m > 0$$

$F = 2dn\,(1 + n - \beta + n^2\beta + \gamma)^2 + \gamma[1 + n^2 + n(2 + \gamma)] > 0$

Cont. Solving the model

- Equilibrium R&D and output per firm are

$$z^*(n) = \frac{n\left[\left(2d - \frac{1}{n}\right)\gamma + 2d(1+n)(1+\beta(n-1))\right]}{F} m > 0$$

$$Z^*(n) = \frac{n^2\left[\left(2d - \frac{1}{n}\right)\gamma + 2d(1+n)\left(1+\beta(n-1)\right)\right]}{F} m > 0$$

$$q^*(n) = \frac{2dn[1+\beta(n-1)]\left[\gamma + (1+n)\left(1+\beta(n-1)\right)\right] + \gamma(\gamma+n+1)}{F} m > 0$$

$$E^*(n) = \frac{n\gamma[2+n+\beta(n-1)+\gamma]}{F} m > 0$$

Comparative Statics

In this section, we examine how the equilibrium values react to changes in the parameters: n (intensity of competition), γ (efficiency/difficulty of innovation), β (degree of spillovers) and d (severity of environmental damage).

$$\frac{\partial \tau^*}{\partial d} = \frac{2\gamma mn(n+1)(\gamma+\beta(n-1)+n+2)\left(1-\beta+\gamma+\beta n^2+n\right)}{F^2} > 0$$

Proposition 1 (EFFECT OF d).

The optimal emission tax τ^* is increasing in the severity of environmental damage d.

Comparative Statics

$$\frac{\partial \tau^*}{\partial n} = \frac{m\begin{bmatrix}-4d^2n^2(2\beta n+1)(-\beta+\gamma+\beta n^2+n+1)^2+2\gamma d((\beta-\gamma)^2-3\beta+3\gamma+\beta(5\beta+1)n^4 \\ +2\beta(\gamma+6)n^3+n^2(2\beta(-3\beta+3\gamma+5)+4)+n(-4\beta+4\gamma+6)+2)+\gamma^2(\gamma+2n+2)\end{bmatrix}}{F^2}$$

Proposition 2 (EFFECT OF n)

The effect of the number of firms n on the optimal emission tax τ^* is described as follows:

I For $d > max\left\{\frac{1}{2n}, d_{n2}\right\}$ there exists a threshold value for $n, \hat{n}_2$, such that the emission tax increasing as $n < \hat{n}_2$ and vice versa.

II For $d \in \left(max\left\{\frac{1}{2n}, d_{n3}\right\}, dn_2\right)$ there exists a threshold value for $n, \hat{n}_3$, such that the emission tax increasing as $n < \hat{n}_3$ and vice versa.

III For $d \in \left(max\left\{\frac{1}{2n}, d_{n4}\right\}, dn_3\right)$ there exists a threshold value for $n, \hat{n}_4$, such that the emission tax increasing as $n < \hat{n}_4$ and vice versa.

IV For $d \in \left(\frac{1}{2n}, dn_4\right)$, the emission tax is decreasing in n.

$dn_2 > dn_3 > dn_4 > 0$ invariant in both β and γ.

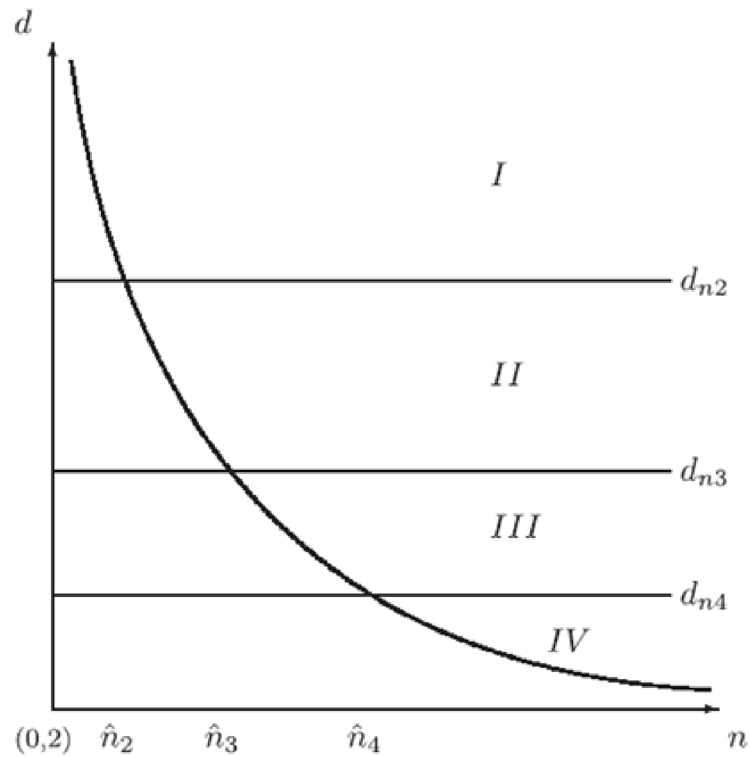


Fig. 1. The effect of n on $\tau^*(n)$.

Comparative Statics

Parts I, II and III identify a 'small/large' number oligopoly effect in relation to the extent of damages: when $n < \hat{n}_i$ ('small'-numbers oligopoly), the emission tax is increasing in n so as to bring about more abatement but also to address the output market distortion while for $n > \hat{n}_i$ ('large'-numbers oligopoly) the emission tax is decreasing in n s competition becomes more intense, partly easing the output and innovation distortions so that a lower emission tax can be justified.

In part IV, the emission tax is decreasing due to damages being insignificant (small d), as with more firms conducting R&D there is less need for incentivizing abatement.

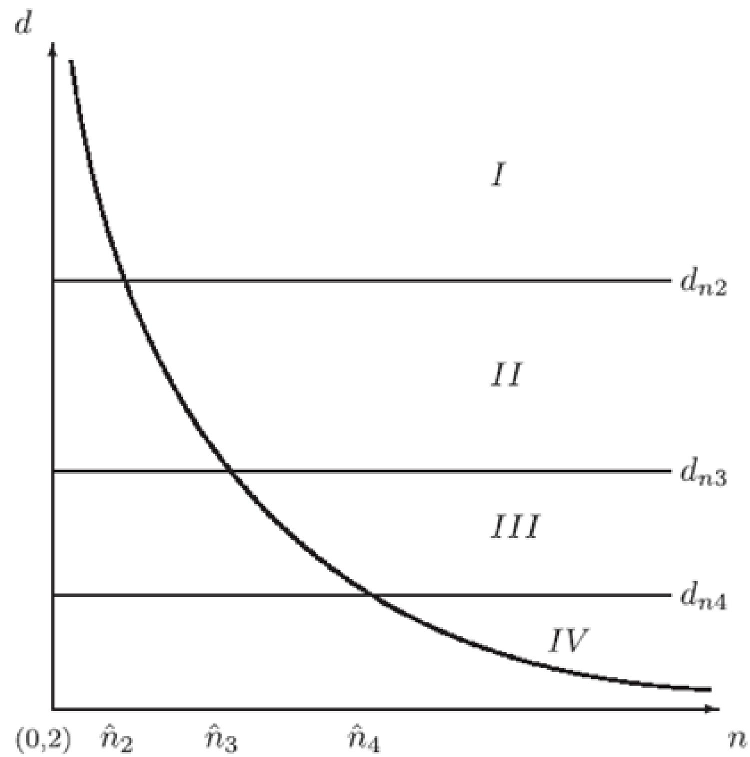


Fig. 1. The effect of n on $\tau^*(n)$.

Comparative Statics

$$\frac{\partial \tau^*}{\partial \gamma} = \frac{\begin{bmatrix} 4d^2n^2(\beta(n-1)+1)\left(1-\beta+\gamma+\beta n^2+n\right)^2+2\gamma dn(1-\gamma \\ (\beta\left(n^2+n-2\right)-2(n+1)(\beta(n-)+1)^2)+\gamma^2(-(n+1)) \end{bmatrix}}{F^2}(n+1)m$$

Proposition 3 (EFFECT OF γ)

The optimal emission tax τ^* is:

i. Increasing in R&D efficiency, γ, for $d \geq d_\gamma^+$,

ii. For $d \in \left(\frac{1}{2n}, d_\gamma^+\right)$, the emission tax is increasing in γ when $\gamma \in (0, \hat{\gamma})$, and decreasing in $\gamma \geq \hat{\gamma}$

When environmental damage d is relatively large, R&D is more important in reducing emissions, so to incentivize firms to engage in emission reduction the emission tax is increasing (part (i)).

For small damages, the emission tax is increasing for relatively easy R&D, but decreasing when R&D is more difficult, still providing incentives for abatement (part (ii)).

Comparative Statics

$$\frac{\partial \tau^*}{\partial \beta} = \frac{2\gamma d n(n^2-1)\left[-2dn\left(\gamma+\beta n^2+n+1-\beta\right)^2+\gamma(-2\beta+2\gamma+n(\gamma+2\beta n+n+4)+3\right]}{F^2} m$$

Proposition 4 (EFFECT OF β)

The effect of the spillover, β,on the optimal emission tax τ^* is described as follows:

S1 For $d \geq max\left\{d_{\beta 0}, \frac{1}{2n}\right\}, \frac{\partial \tau^*(n)}{\partial \beta} \leq 0$,

S2 For $d \epsilon \left(max\left\{d_{\beta 1}, \frac{1}{2n}\right\}, d_{\beta 0}\right), \frac{\partial \tau^*(n)}{\partial \beta} \gtreqless 0$ for all $\beta \gtreqless \beta^+$ with $\beta^+ \epsilon (0,1]$,

S3 For $d \epsilon \left(\frac{1}{2n}, d_{\beta 1}\right), \frac{\partial \tau^*(n)}{\partial \beta} > 0$.

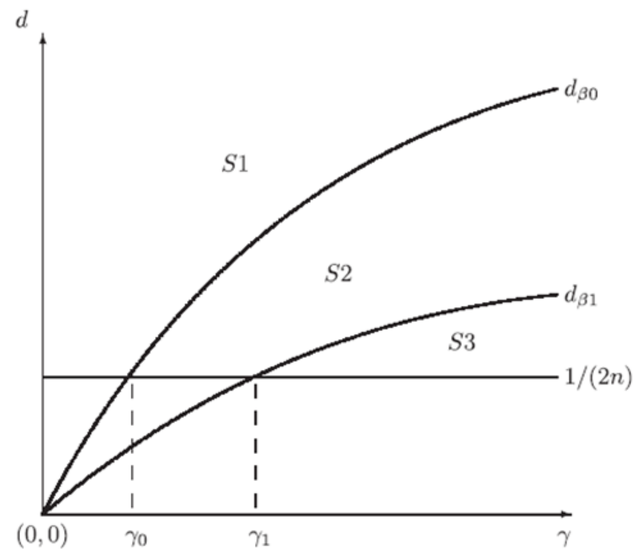


Fig. 2. The effect of β on $\tau^*(n)$.

Comparative Statics

- In area S1 a higher spillover is associated with a reduction in the emission tax as the appropriability problem is exacerbated and hence points to a lower tax and a lower incentive to innovate.

- In area S3, the opposite occurs which appears counter-intuitive; however, in this area R&D is more difficult (higher γ) and damages are small (low d) so than an increase in the emission tax is needed to provide the necessary incentive for abatement.

- Area S2 is intermediate between areas S1 and S3 where the direction of the change in the emission tax depends on the magnitude of the spillover.

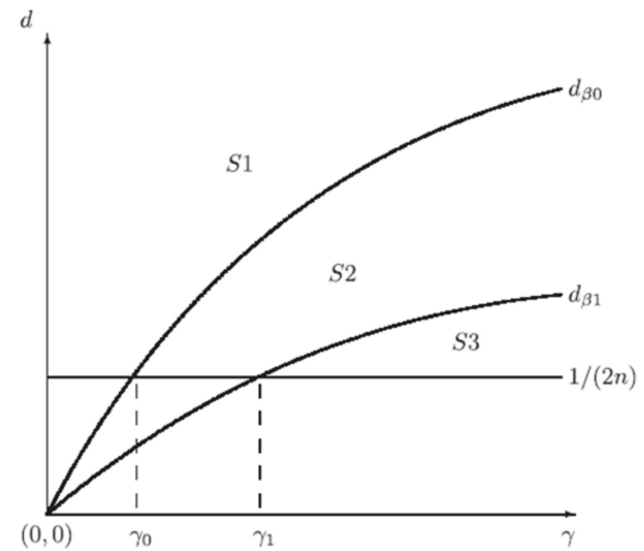


Fig. 2. The effect of β on $\tau^*(n)$.

Comparative Statics

$$\frac{\partial e^*}{\partial n}, \quad \frac{\partial e^*}{\partial \beta}, \quad \frac{\partial e^*}{\partial \gamma}, \quad \frac{\partial e^*}{\partial d}$$

Proposition 5

Individual equilibrium emissions are:

i. Decreasing in the number of firms.
ii. Decreasing in spillovers.
iii. Increasing in R&D efficiency.
iv. Decreasing in the severity of environmental damage.

Parts (ii) and (iv) are a direct consequence of the effects identified in Proposition 4 (S1 and S2) and Proposition 1 above.

Parts (i) and (iii) are more complex as they combine the non-monotonic effect of the changes in the emission tax and the direct and indirect effects associated with changes in R&D and output.

It appears that in part (i) the output direct effect is dominating while in part (iii) the R&D direct effect dominates.

Competition and "GREEN" Innovation

- The main research question:

The Relationship between Competition and 'GREEN' Innovation

$$Z^*|_{\beta=0} = \frac{\gamma n^2\left[\left(2d-\frac{1}{n}\right)\gamma+2d(1+n)\right]}{F_0}m > 0$$

where $F_0 \equiv F|_{\beta=0} > 0$.

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

$$\left.\frac{\partial Z^*}{\partial n}\right|_{\beta=0} > 0$$

Lemma 1

In the absence of R&D spillovers there is a positive relationship between competition and "GREEN" innovation, i.e., $\beta = 0$.

Cont. Competition and “GREEN” Innovation

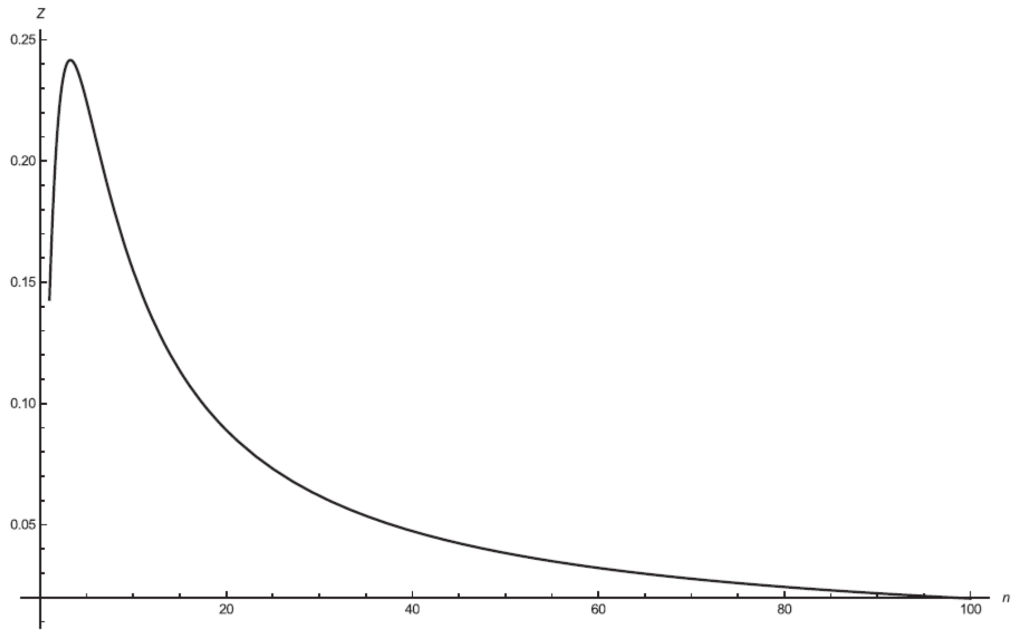


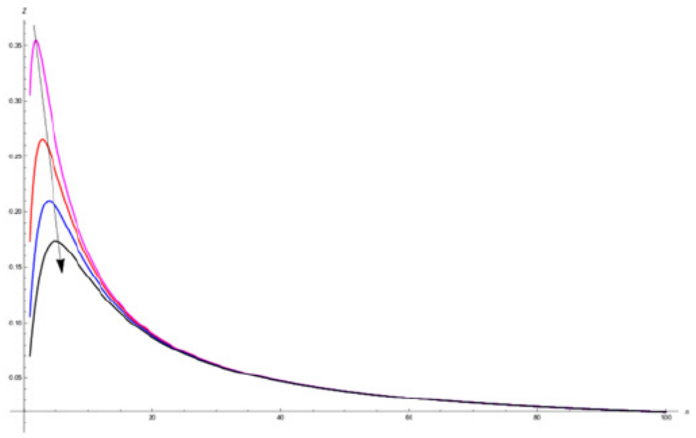
Fig. 3. An Inverted-U Relationship ($m = 1$, $\gamma = 5$, $\beta = 0.5$, $d = 5$).

Proposition 6 (COMPETITION AND “GREEN” INNOVATION)

For any given d in the presence of positive R&D spillovers, $\beta \in (0,1]$, the aggregate “green” innovation $Z^*(n)$ is concave and single peaked. A sufficient condition for its maximum to occur at $n \geq 2$ is $\beta \in (0, min\left\{\frac{1+c}{5}, 1\right\}]$.

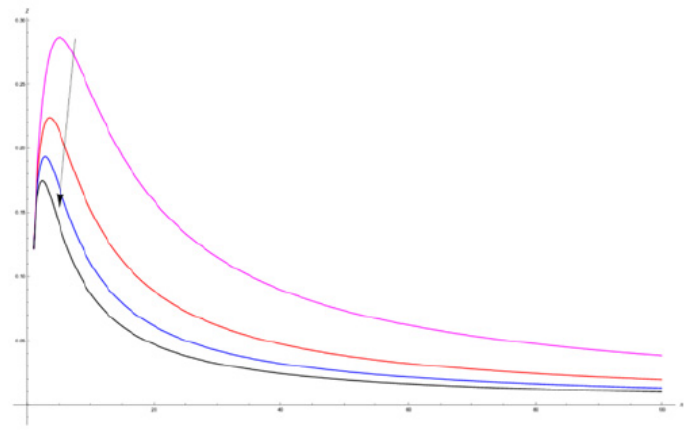
Cont. Competition and "GREEN" Innovation

Variations in γ



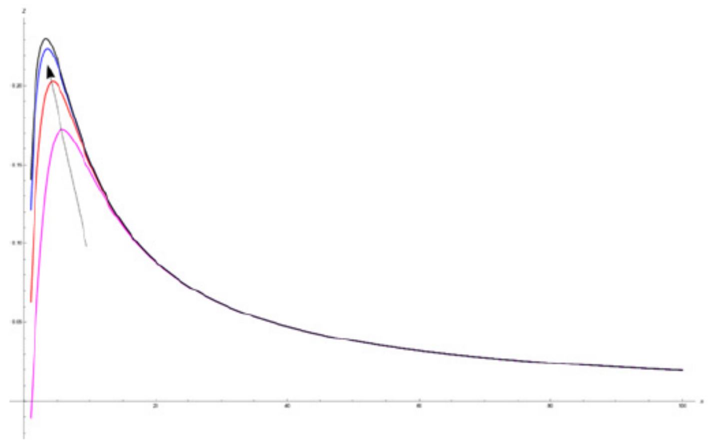
$\beta = 0.5, d = 5$
$\gamma = \{1, 3, 6, 10\}$

Varations in β



$\gamma = 5, d = 5$
$\beta = \{0.25, 0.5, 0.75, 1\}$

Variations in d



$\gamma = 5, \beta = 0.5$
$d = \{0.3, 1, 5, 50\}$

Agg. Innovation, Competition & Social Welfare

Social welfare at equilibrium is

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

As the number of firms tends to infinity

$$\lim_{n\to\infty} W^* = \frac{m^2}{2} > W^*$$

There is a divergence between the market structure necessary to maximize social welfare (perfect competition) and the market structure that maximizes "green innovation" (oligopolistic, imperfect competition). Exploring this issue in more detail is left for further research.

Conclusion

In conclusion , we have found an inverted-U relationship between "green" innovation and competition, which is driven by the presence of R&D spillovers.