Innovation and Market Structure in General Equilibrium

by

Joshua S. Gans *and* Robin Stonecash*

This paper looks at the interrelationships between innovation and market structure in a static general equilibrium model. In contrast to previous work in industrial organisation and growth theory, this paper presents a robust conclusion that over-innovation is possible. This results from the assumption that R&D uses final goods rather than labour, which means that higher levels of R&D stimulate demand, rather than depleting resources available for final goods production.

* Melbourne Business School, University of Melbourne and Australian Graduate School of Management, University of New South Wales, respectively. We thank Maxim Engers, Murray Kemp, Shannon Mitchell, Sjak Smulders and Trevor Stegman for helpful discussions. All errors remain our own.

1. Introduction

Theoretical studies of the interdependency between market structure and innovation fall into two classes. The first is the partial equilibrium analyses that view innovation as generated by in-house R&D expenditures. A seminal paper in this literature is Dasgupta and Stiglitz (1980). The second class is associated with endogenous growth theory. This literature considers the general equilibrium implications of innovations when knowledge spillovers between firms are important (Romer, 1990; Barro and Sala-I-Martin, 1995). This literature often neglects the strategic implications of firm interaction that arise from an in-house R&D perspective.

There have been a few attempts to integrate the strategic implications of in-house R&D into general equilibrium models. The work of Van De Klundert and Smulders (1995, 1993) and Perotti (1995) represent examples of this. They confirm the general conclusion of the industrial organisation and growth literature that *average* innovation is too low and concentration too high relative to the social optimum. However, each of these papers generates this result assuming a very specific form of R&D technology — the production of in-house knowledge is purely labour intensive.

In this paper, we show that this conclusion is not robust. Using a static general equilibrium model, it is shown that, the average level of innovation can exceed the social optimum. This is because we assume that R&D uses final goods rather than labour. This is the "lab-equipment" specification of Rivera-Batiz and Romer (1991). This assumption means that greater R&D, rather than depleting the resources available for final good production and, therefore, reducing effective market size, stimulates demand. Hence, it is possible that even the duplication of R&D expenditures under competitive situations can raise the incentives of firms to conduct R&D. This, however, represents a situation in which the private returns to entry exceed the social returns and hence, the average as well as the total level of innovation can exceed socially optimal levels.

2. Basic Model

This section presents the basic set-up and notation for the analysis to follow. Note the specific sectoral structure assumed here could easily be manipulated without altering the results to follow. We choose this specification as we believe it to be the simplest form to capture the interactions between innovation, competition and labour or resource market equilibria.

2.1. Sectoral Structure and Technology

We model a closed economy that consists of two production sectors — an upstream and a downstream sector. Since our focus is on the market structure implications of innovation, we assume (as does Arrow, 1962), that the downstream sector is perfectly competitive with all firms being price takers. These firms produce a homogeneous final good denoted Y, using a Cobb-Douglas technology, employing both labour, L_Y, and a composite of intermediate inputs, X:

$$Y = X^{a} L_Y^{1-a}, \quad 1 > a \geq 0.$$

This production function exhibits constant returns to scale.[1] In addition, it is assumed that the downstream sector is competitive with all firms being price takers. This final good is assumed to be the numeraire.

Households consume final goods not used in production and supply one unit of labour inelastically for which they receive a competitive wage, w. The total labour endowment is $\overline{L}$. The existence of this labour constraint means that the parameter, $\overline{L}$, is a useful proxy for examining market size effects.

Intermediate inputs are produced in the upstream sector. In this paper, we assume that these inputs are homogeneous. The total level of intermediate inputs produced is:

$$X = \sum_{i=1}^{N} x_i ,$$

where i indexes a firm and N is the total number of upstream producers.

Profit-maximising final goods producers will choose their labour and intermediate input demands to satisfy the following condition (using the Cobb-Douglas assumption):

$$\frac{wL_Y}{PX} = \frac{1-a}{a},$$

where P is the marginal cost of producing a unit of the composite, X:

$$P = \min_{\{x_i\}_{i=1}^{N}} \left\{ \sum_{i=1}^{N} p_i x_i \,\middle|\, \sum_{i=1}^{N} x_i^{\frac{s-1}{s}} = 1 \right\} = \left(\sum_{i=1}^{N} p_i^{1-s} \right)^{\frac{1}{1-s}} .$$

From this we can determine individual firm demand,

$$x_i = X \left(\frac{P}{p_i} \right)^{s},$$

where use is made of the assumption of constant returns to scale in final good production.

[1] The Cobb-Douglas assumption is not critical here. The results could also be presented using a general constant returns to scale production function with the restrictions discussed by Ciccone and Matsuyama (1996).

2.2. Research Technology

Firms in the upstream sector are potential innovators. They produce goods using only labour according to a simple linear production function:

$$\hat{x}_i = \frac{\hat{l}_i}{\Psi(\hat{F}_i)}.$$

F_i represents the level of process technology for firm i. The choice of F_i itself, is assumed to be endogenous. Higher choices of F_i mean a lower labour requirement; that is, $\Psi'(F_i) < 0$ with a choice of zero fixed costs making production prohibitively costly, i.e., $\Psi(0) \to \infty$ as $F_i \to 0$.[2] We follow the assumptions of Dasgupta and Stiglitz (1980) and Gans (1998a, 1998b), by having a rich technology space, with $F_i \in \Re^+$.[3]

By choosing higher levels of F_i firms raise the fixed cost incurred. We assume that innovating to a level, F_i, requires the use of F_i units of the final good. Thus, the research technology assumed here is akin to Rivera-Batiz and Romer's (1992) "lab-equipment" model — the production of technology uses inputs with the same intensity as final good production.[4]

It is convenient to specify a functional form for Ψ:

$$\Psi(F_i) = F_i^{-q}.$$

This is the form used by Dasgupta and Stiglitz (1980), which is convenient because θ describes the elasticity of unit cost reductions with respect to research expenditures.

An alternative specification for modelling the impact of research and development would be to consider product innovation. This would be done by assuming that research

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[2] Each result to follow requires only that the marginal labour requirement when $F_n = 0$ be some positive constant.

[3] Dasgupta and Stiglitz (1980) and Vassilikas (1989) analyse continuous mechanisms for technological choice but in very different contexts to that here.

[4] The implications of this assumption on the nature of fixed costs is robust to allowing the firm to choose the intensity with which labour and final goods are used in R&D (Gans, 1997).

resulted in products of higher quality (Grossman and Helpman, 1991; Sutton, 1995). Such a specification is equivalent to the process innovation story here and so it simplifies matters to focus on one dimension exclusively.[5]

The presence of fixed costs, while being endogenous, means that the upstream sector cannot be perfectly competitive. That said, the competitiveness of that sector is potentially diverse. Therefore, below we consider a range of market structures ranging from those with exogenous entry barriers to those with no entry barriers. Using the common framework here we can then analyse the welfare implications of alternative structures in a general equilibrium setting.

3. Equilibria

We begin our discussion of the alternative implications of market structure by looking at the case of homogeneous products. Intermediate inputs are perfect substitutes for one another. Because of this, to simplify matters, we will assume that there are no (explicit) start-up costs to entry by any firm. In this setting, we can contrast the Cournot (with and without entry barriers) and Bertrand (contestable natural monopoly) outcomes.

3.1. Cournot Conjectures (Fixed *N*)

We begin with the situation in which N is fixed. Since the final good sector is perfectly competitive, factor allocations in this sector must satisfy the Cobb-Douglas optimising condition above. Given the labour market clearing condition:

$$\overline{L} = L_Y + L_X ,$$

[5] Athey and Schmutzler (1995) consider both product and process innovation and find that both types of innovation are complements at a firm decision level.

that price equals marginal cost across sectors (ie., $P = w$) and the fact that wages equal the marginal product of labour in final good production, then:

$$w = (1-a)\, X^{a} L_Y^{1-a}.$$

From this we can obtain the allocations of labour and intermediate inputs in the final sector in terms of an aggregate of upstream innovation choices,

$$L_Y = \bar{L}\left(\tfrac{1-a}{a} + \Im\right)^{-1}\left(\tfrac{1-a}{a}\right),\ X = \bar{L}\left(\tfrac{1-a}{a} + \Im\right)^{-1}, \text{ and } L_X = \bar{L}\left(\tfrac{1-a}{a} + \Im\right)^{-1}\Im.$$

where

$$\Im = \sum_{i=1}^{N} \Psi(F_i).$$

Suppose that both potential entrants and incumbent firms hold Cournot conjectures regarding the behaviour of others. They determine their quantity and innovation decisions simultaneously holding those of others as given. Their profit functions are:

$$p_i = \left(L_Y\left(\tfrac{1-a}{a}\right)\left(x_i + \sum\nolimits_{j\neq i} x_j\right)^{-1} - \Psi(F_i)\right) w x_i - F_i.$$

When firm i makes its choices, in addition to holding fixed the quantities and innovation levels of other firms j ¹ i, it holds wages and labour demand in the final good sector as fixed. Under these assumptions (as in Dasgupta and Stiglitz, 1980), the optimal price and innovation levels are determined by:

$$p_i = \left(1 - e\frac{x_i}{X}\right)^{-1} w\Psi(F_i)$$

$$-w\Psi'(F_i)\, x_i = 1.$$

Note that the sectoral inverse elasticity of demand, e, is:

$$e(X) \equiv -X\frac{p'(X)}{p(X)} = 1.$$

Moreover, suppose (following Dasgupta and Stiglitz, 1980) that the equilibrium is symmetric. In this case, $X=Nx$, where x is the symmetric individual firm quantity produced. In this case,

$$P = \left(\tfrac{N}{N-1}\right) w\Psi(F),$$

where F is the symmetric choice of innovation.

Using this (in conjunction with labour market clearing) we find that:

$$L_Y = \bar{L}\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1} \text{ and } X = \bar{L}\Psi\left(F\right)^{-1}\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1}.$$

From this we can find equilibrium wages as a function of the innovation level and industry concentration, N:

$$w = a^{a}\left(1-a\right)^{1-a}\left(\tfrac{N-1}{N}\right)^{a}\Psi\left(F\right)^{-a}.$$

Observe that wages rise with the average level of innovation among firms and with the number of firms in the industry. This is because both of these raise the demand for labour by intermediate input firms.

Once again, in order to obtain comparable results it helps to use a functional form. Using the functional form for Ψ above, firms choose the following level of innovation:

$$F_i = \left(a^{a}\left(1-a\right)^{1-a}\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1}\left(\tfrac{N}{N-1}\right)^{a}\tfrac{q}{N}\bar{L}F^{q(1+a)}\right)^{\frac{1}{1+q}},$$

where it should be recalled that F is the symmetric choice of innovation by all firms. Interestingly, maximising out for price-quantity choices, individual innovation levels are increasing in the level of innovation chosen by other firms (F) and the market size ($\bar{L}$). This strategic complementarity comes from the fact that wages and the industry demand curve are determined endogenously. When wages and the industry demand curve are fixed (i.e., industry production does not have economy-wide resource effects), then the first-order effects of other firm’s innovation level on the returns to own innovation are zero. However, to the extent that a decision to raise own innovation is complementary with raising output, since output decisions are strategic substitutes, this indirectly reduces the returns to innovation. When wages and industry demand are endogenous, the demand-creation effects of innovation outweigh these Cournot effects. Ultimately, greater innovation raises the incentives for further innovation.

On the other hand, increased competition lowers the returns to innovation. This is because new entrants take market share from incumbents and this is not compensated for by the increase in wages and hence, industry demand that competition stimulates. This can be more clearly seen by looking at the equilibrium innovation level:

$$F^{C} = \left(a^{a}(1-a)^{1-a}\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1}\left(\tfrac{N}{N-1}\right)^{a}\tfrac{q}{N}\overline{L}\right)^{\frac{1}{1-qa}}.$$

It is quite easy to show that if $N > 2$, as N rises, the equilibrium amount spent on research falls (regardless of the other parameter values). Therefore, despite the additional wage effect, the conclusions of Dasgupta and Stiglitz (1980) regarding the negative effects of competition on average innovation remain.

In a homogeneous product industry it is socially optimal to have low concentration given the increasing returns associated with innovation. Nonetheless, we can respect the entry barriers implicit in the fixed N assumption and suppose that the planner chooses the level of innovation subject to those constraints. In this case, consumption is:

$$C(N,F) = \overline{L}\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1}\Psi(F)^{-a}\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{1-a} - NF .$$

The socially optimal level of innovation is determined by the first order condition:

$$F^{SOC}(N) = \left(a^{a}(1-a)^{1-a}\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1}\left(\tfrac{N}{N-1}\right)^{1-a}\tfrac{q}{N}\overline{L}\right)^{\frac{1}{1-qa}}.$$

It is very easy to see that $F^{SOC}(N) > F^{C}(N)$, for all $N > 1$. Hence, there is underinvestment in innovation.

3.2. Cournot Conjectures (Free Entry)

What happens when N is determined endogenously by allowing for free entry and exit of firms? Observe that in the previous case equilibrium profits are:

$$p(N) = \left(P - w\Psi\left(F^C\right)\right)x - F^C$$
$$= \left(\tfrac{1}{N-1}\right)a^a\left(1-a\right)^{1-a}\left(\tfrac{N-1}{N}\right)^a \Psi\left(F^C\right)^{-a}\tfrac{1}{N}\bar{L}\left(\left(\tfrac{N}{N-1}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1} - F^C.$$

Setting this equal to zero, we can determine the equilibrium N:

$$N^C = \frac{1+q}{q}.$$

This result is exactly the same as the partial equilibrium result of Dasgupta and Stiglitz (1980). They show that, when q and e depend on industry output X:

$$N^C = e\left(X^C\right)\frac{1+q\left(X^C\right)}{q\left(X^C\right)},$$

where e is the elasticity of industry demand. This is a general phenomenon in models with endogenous sunk costs: that firms will "escalate" research in order to forestall entry (Sutton, 1995). Concentration is higher, the more efficient is the research technology. Moreover, equilibrium concentration is independent of industry demand and factor price considerations. As such, it is clear why, by making these endogenous in a general equilibrium setting, this independence result is preserved. Nonetheless, observe that the size of the market ($\bar{L}$) and the efficiency of the research technology (q), both raise the equilibrium average level of innovation:

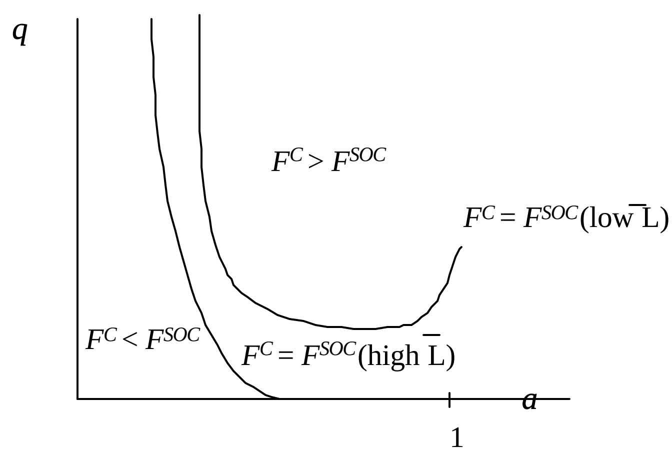
$$F^C(N) = \left(a^a\left(1-a\right)^{1-a}\left(\left(\tfrac{1+q}{q}\right)\left(\tfrac{1-a}{a}\right)+1\right)^{-1}\left(\tfrac{q}{1+q}\right)^a\tfrac{1}{1+q}\bar{L}\right)^{\frac{1}{1-qa}}.$$

Dasgupta and Stiglitz (1980) found that under free entry, average innovation was less than the social optimum but that industry research expenditures could exceed the optimal level. This is because average innovation mattered for efficiency and this expenditure was duplicated among firms. This latter effect was a social cost. In our model, here, if a = 1 and labour is not used in final good production, then it is easy to show that average innovation in equilibrium is less than the social optimum. That is,

$$F^{SOC} = \left(q\bar{L}\right)^{\frac{1}{1-q}} > \left(\frac{q}{\left(1+q\right)^2}\bar{L}\right)^{\frac{1}{1-qa}} = F^C .$$

However, when a < 1, it is possible that the *average* level of innovation as well as the total research expenditure could *exceed* the socially optimal level. By putting F^C into the first order condition for a social optimum, and examining when this value is negative we can determine the range of parameters for which there is average overinvestment in innovation. Based on numerical results this range of parameters is depicted in Figure One.

<u>Figure One</u>



The intuition behind this result is subtle. When a = 1, as the market size rises, there are increased incentives to “escalate” innovation to forestall entry. However, while this does prevent further entry, the desired expansion in output is constrained by the fixed labour supply to the industry. When a < 1, this constraint is lifted and firms in the industry are free to compete labour away from the final goods sector in order to raise output and innovation. This allows equilibrium industry demand to exceed its optimal level because of the resulting distortion in factor prices from the competition in the upstream sector. This effect is stronger, the more efficient is the research technology allowing for escalation in response to entry. This offsets other effects caused by falling prices and leads to innovation that is greater than the social optimum. To be clear, it is the general equilibrium structure of the model that allows an over-innovation result, so that competition can distort the sectoral allocation of scarce factors.

This result hinges critically on the "lab equipment" nature of R&D investment. What this means is that greater total R&D expenditure has a demand increasing effect as opposed to a pure resource depleting effect as would occur if R&D were purely labour intensive. Van De Klundert and Smulders (1993) use this latter formulation and preserve the conventional under-investment result. Given this difference in results, it becomes important to look at a more reasonable specification for R&D investment. In Gans (1997), the choice of inputs into R&D is endogenised and it is shown that as the market size grows, R&D becomes more final good as opposed to labour intensive. This is because the relative price of final goods to wages falls at larger scales of production. This property would be preserved for the result of this paper. Therefore, since over-investment is more likely at high market sizes it can be concluded that this is a robust conclusion.

3.3. Bertrand Conjectures (Free Entry)

When firms hold Bertrand conjectures, because of the increasing returns nature of production, only one firm will survive in a homogeneous product industry. Thus, the outcome is akin to a contestable natural monopoly, so long as there is one potential entrant. In this case, prices are equal to average cost:

$$P = w\Psi(F) + \frac{F}{X}.$$

In this case, the level of innovation will be the same as the social optimum. The reason for this is the incumbent firm will be forced to raise the level of innovation so long as there are efficiency gains to be had in the downstream sector. This mirrors conclusions of Moriguchi (1994).[6]

4. Conclusions and Future Directions

There are a number of interesting directions this paper could head in. First, as Sutton (1995) notes, industries in which firms have high R&D intensities tend to be characterised by product differentiation. Therefore, a natural extension would be to consider a differentiated products model for intermediate inputs and repeat the exercise conducted in this paper. Second, the strategic use of innovation to deter entry in a dynamic game could also have interesting general equilibrium effects. Finally, it would be interesting to investigate the possibility that innovation and competition in one sector could distort the level of innovation conducted in order sectors that are perhaps organised with regulated monopolies.

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[6] Note, however, the contrary predictions of Gans and Quiggin (1997) when there exists an entrepreneurial fringe.

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