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On the Welfare Effects of Productivity Catch-Up by Laggard Firms

by

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Abstract

The substantial within-industry variation in firm productivity typically observed in the data suggests that there is ample scope for productivity catch-up by laggard firms. We analyse the normative effects of such catch-up. In the short run, where firms' process technologies are fixed, catch-up can reduce social welfare if the initial productivity gap between firms is sufficiently large (the Lahiri/Ono effect). However, in the long run, where firms invest in process R&D to maximize profits, social welfare jumps upwards following catch-up if it causes the major firm's R&D spending lead to grow. Both qualitative insights appear quite general.

JEL classifications: D61, L13, O33.

Keywords: productivity catch-up, social welfare, process R&D.

Outline

Non-Technical Summary

Our starting-point is the stylized fact that within-industry variation across firms in productivity is typically very large. For example, Haskel and Martin (2002) show that, in 2000, the average labour productivity gap in UK manufacturing industries between the 90th and 10th percentile plants was above 5 to 1. Within-industry productivity spreads are typically “large” in at least two specific senses: first, in relation to wage dispersion; and second, in the sense that they, rather than between-industry differences, account for most of the overall productivity dispersion across firms.

These large within-industry productivity gaps suggest that there is ample scope for laggard firms to catch up, in productivity terms, with industry leaders. In this paper, we analyse the welfare effects of productivity catch-up by a minor firm in a duopoly. The catch-up takes the form of an exogenous narrowing of the initial marginal-cost gap between the firms. In the short run, where the firms’ process technologies are fixed, “helping” the minor firm produces the Lahiri/Ono (1988) result. If the initial productivity gap is sufficiently large, then reducing the minor firm’s marginal cost causes social welfare to fall because it causes a socially inefficient reallocation (i.e., major-to-minor) of initial production.

In the long run, the firms’ process R&D investments are endogenously determined to maximize profits. If “helping” the minor firm causes the major firm’s R&D spending lead over its rival to grow (through changes in R&D investment patterns), then social welfare jumps upwards. By extending the major firm’s R&D spending lead, reducing the initial productivity gap between the firms raises social welfare discretely because it widens the equilibrium productivity gap. This widening provokes a socially efficient reallocation (i.e., minor-to-major) of initial production levels.

Although our quantitative results are derived using a rather stylized model, we argue that our qualitative insights will survive in more general contexts. Given this expectation, our findings are most clearly illustrated using a simple model.

1 Introduction

Our starting-point is the stylized fact that within-industry variation across firms in productivity is typically very large. For the UK, Haskel and Martin (2002) examine productivity dispersions within manufacturing industries over 1980-2000. They show that, in 2000, the average labour productivity gap in manufacturing industries between the 90th and 10th percentile plants was above 5 to 1. The same gap in terms of total factor productivity (TFP) was about 1.6 to 1.[1] Moreover, Haskel and Martin show that, if anything, the typical productivity spread in UK manufacturing increased between 1980 and 2000.

Oulton (1998) provides two specific senses in which the productivity spreads within UK manufacturing industries are "large." First, using company accounts data for the whole UK economy, Oulton shows that, in 1993, dispersion across firms in labour productivity was about 50% higher than in weekly earnings. Second, Oulton shows that about three quarters of labour-productivity dispersion across firms is due to differences in productivity between firms in the same narrowly-defined (i.e., 4-digit) industry. Moreover, although Haskel and Martin restrict their attention to UK manufacturing, the stylized fact that within-industry productivity dispersion is "large" appears to be robust across both other broad sectors of the UK economy (e.g., services[2]) and other countries (e.g., Dwyer, 1998, on US textile industries).

These large within-industry productivity gaps suggest that there is ample scope for laggard firms to catch up, in productivity terms, with industry leaders. In this paper, we analyse the welfare effects of productivity catch-up by laggards. We introduce a distinction in logical time between the short and long runs, and we examine the effects of catch-up over those two horizons. In the *short run*, firms' process technologies are given, and catch-up moves laggards towards the static industry technology frontier, whose position is determined by the industry leader's technology. However, in the *long run*, the industry's technology frontier can move outwards as a result of firms' R&D investment decisions, which are then endogenously determined to maximize profits. Therefore, our notion of short vs. long run has its counterpart in the familiar normative concepts of static vs. dynamic efficiency (Tandon, 1984; Qiu, 1997).

[1] TFP measures the *joint* productivity of a given bundle of inputs (e.g., capital and labour). It reflects a firm's "technical knowledge."

[2] Oulton (1998) reports that the within-industry dispersion across firms in labour productivity is around 40% *lower* in UK manufacturing than elsewhere in the UK economy.

In reality, productivity catch-up by laggards can occur for a variety of reasons – for example, as a result of purposive actions by firms and governments, and due to "natural" processes of technology diffusion and imitation. One of the stated reasons why countries like the UK have been so keen to host foreign direct investment (FDI) is that foreign-owned plants typically exhibit higher labour productivity than domestically-owned ones within the same industry (Griffith *et al.*, 2004).[3] To the extent that domestic/foreign TFP differences underlie these observed labour productivity gaps, host governments hope that inward FDI will lead to foreign-to-domestic productivity spillovers, which improve the performance of domestic firms (Görg and Greenaway, 2004). Moreover, independently of the foreign sector, leader-to-laggard spillovers can occur over time within an industry as laggards learn from leaders and technology diffuses (Malerba, 1992). Finally, the deliberate actions of firms can contribute to bringing laggards up to date with industry best practice. Joint ventures, technology licensing, and trade associations are all examples of mechanisms through which this can occur, and they are all empirically common.

Because our primary concern is not the incentives of governments and firms to foster catch-up by laggards, we do not model the catch-up process and its associated costs explicitly.[4] Rather, we take a degree of catch-up as given and investigate its normative effects.[5] To study the effects of "helping" minor firms to move towards the technology frontier, we model R&D competition in a two-stage duopoly: in the first stage, the firms choose their investment levels in process R&D; and, in the second, they compete à la Cournot on the product market. The firms are asymmetric both initially (because their initial marginal costs differ, as a result of pre-game history) and in terms of their investment opportunities in process R&D, which is a binary choice where the firms' R&D sunk costs and innovation sizes in general differ. Our equilibrium concept is subgame perfection, and we restrict the inter-firm productivity gap to ensure that interior Cournot equilibria always exist. Our modelling structure therefore extends the familiar two-stage analyses of R&D competition (i.e., process R&D choices, followed by market competition) by relaxing

[3] Ferrett (2006) surveys the empirical literature on domestic/foreign productivity gaps.

[4] For a simple analysis of how foreign-to-domestic spillovers affect foreign firms' inward FDI incentives, and a discussion of possible spillover channels, see Ferrett (2005).

[5] Our welfare standard is "social welfare," the unweighted sum of industry profits and consumer surplus. Therefore, our results will have implications for the willingness of a benevolent government to promote catch-up. Obviously, if catch-up reduces social welfare then, even with costless policy intervention, it should not be promoted.

the conventional assumptions of initially symmetric firms and symmetric process R&D opportunities across firms.[6] Given the substantial within-industry productivity spreads typically oberved in the data, and discussed at the outset, we argue that this represents an important advance towards realism.[7] Our model complements that of Boone (2001), who analyses the effect of marginal-cost asymmetries between firms on their willingness to bid for the patent on a process innovation, by allowing both firms to innovate simultaneously.[8]

We begin by analysing social welfare in the short-run case where firms' process technologies are given. Here, "helping" the laggard (minor) firm by slightly reducing its marginal cost has an intuitive impact on the individual components of social welfare: consumers and the laggard firm itself both gain, but the productivity leader loses. However, when these effects are aggregated, social welfare *falls* if the productivity gap is sufficiently large.[9] The intuition for this perverse effect is that, due to strategic substitution on the product market in Cournot competition, the laggard firm steals business from the leader when it is "helped," which is a socially inefficient redistribution of initial production. If the inter-firm productivity gap is sufficiently large, then the increased production costs on the output so redistributed can drag overall social welfare downwards.

Turning to the long run, where the firms choose their process R&D levels before Cournot competition, the normative effects of "helping" the laggard are more complex. If slightly cutting the minor firm's marginal cost induces a change in equilibrium R&D decisions, then social welfare changes discretely (because process R&D investment itself is a discrete variable). If "helping" the minor firm causes (via changes in equilibrium R&D

[6] Important papers in that literature that use these symmetry assumptions include Brander and Spencer (1983), d'Aspremont and Jacquemin (1988), Kamien *et al.* (1992), Suzumura (1992), and Leahy and Neary (1997).

[7] Mills and Smith (1996) make the important point that an asymmetric game is *unnecessary* to generate asymmetric equilibria and explain asymmetric observations. However, our model *assumes* asymmetries between firms in initial conditions (accumulated R&D stocks) and R&D choice sets for two reasons. First, such asymmetries appear empirically significant. Second, it seems reasonable to assume that accumulated R&D stocks ("initial conditions") are largely independent of the (possibly small) catch-up "intervention." Most obviously, the catch-up under analysis could be unanticipated. However, even if it was (at least partially) foreseen, the catch-up "intervention" may not have affected R&D investments in the past – e.g., because Knightian uncertainty (as opposed to risk) shortens firms' "objective" planning horizons. (See Röller and Sinclair-Desgagné, 1996, for discussion of the causes of inherited asymmetries.)

[8] Our paper addresses similar questions within the "R&D competition" literature to those that Boone considers within the "patent race" tradition.

[9] Lahiri and Ono (1988) first highlighted this effect. See also Zhao (2001).

behaviour) the major firm's R&D spending lead over its rival to widen, then social welfare jumps upwards.[10] If it causes the major firm's R&D spending lead to grow, then *reducing* the initial (ex ante) productivity gap between the firms by "helping" the minor firm raises social welfare discretely because it *widens* the equilibrium (ex post) productivity gap. Because of strategic substitution in outputs, this widening provokes an efficient reallocation (minor-to-major) of initial production levels.

We also explore, in the long-run case, the monotonicity properties of equilibrium social welfare in the minor firm's initial marginal cost. We are interested in isolating conditions under which equilibrium social welfare is monotonically decreasing in the minor firm's initial marginal cost so that "helping" it is *always* beneficial. If the minor firm invests in R&D, then social welfare is independent of its initial marginal cost because the specification of the process innovation is independent of initial conditions. However, if the minor firm does not undertake R&D, then social welfare is U-shaped in its initial marginal cost, with an upward slope for a sufficiently large productivity gap (as explained above). Whilst the curvature, for any pair of R&D choices, of the social welfare function depends on the firms' marginal costs and is independent of the level of any R&D sunk costs incurred (because these enter social welfare additively), the level of initial marginal cost at which the minor firm is indifferent towards R&D is increasing in its R&D sunk cost. This occurs because "helping" the minor firm reduces the *size* of its process innovation and therefore also its willingness to invest in R&D. Therefore, if its R&D sunk cost is sufficiently small, the minor firm invests in R&D for all levels of its initial marginal cost where social welfare would otherwise be upward-sloping. In consequence, equilibrium social welfare is monotonically decreasing in the minor firm's initial marginal cost over intervals where the firms' equilibrium R&D choices are fixed (and therefore equilibrium social welfare is continuous).

When the fact that, in a short-run context, "helping" minor firms could cut social welfare was first pointed out (Lahiri and Ono, 1988), the observation was used to rationalize the industrial policies pursued by the Japanese Ministry of International Trade and Industry (MITI) in the postwar period, which often favoured major firms over minor ones. An example was MITI's practice of granting major firms better access to new (often imported) technologies, thus widening the gap between leaders and laggards (Lahiri and

[10] Specifically, the major firm's R&D spending lead rises between equilibria if it takes up R&D plans and/or the minor firm abandons them.

Ono, p. 1201).[11] Such interventionist industrial policies are now much less popular with governments, and the predominant policy focus is on fostering "competition" (DTI, 2001). Our analysis also highlights the potential long-run gains from intensified "competition," although the mechanism is perhaps unexpected. Intensifying "competition" by "helping" minor firms and narrowing the initial productivity gap can substantially boost long-run (equilibrium) social welfare if it causes the major firm's R&D spending lead to grow and thereby widens the long-run productivity gap. Therefore, an interesting relationship can be discerned between developments in formal research and in policy practice.

The remainder of the paper is organized as follows. The next section formally describes our two-stage game of R&D competition and defines our welfare measures. In section 3 we present the game's perfect equilibria and we analyse the effects of "helping" the minor firm, distinguishing between the cases where the major firm's R&D is cheap and costly. Finally, section 4 concludes.

2 Model

We analyse R&D competition in a linear Cournot duopoly where the firms' cost structures are asymmetric using the following two-stage game of complete information.[12] In *stage one*, the duopolists simultaneously and irreversibly choose whether to invest in process R&D (R) or not (N). By investing in R&D, firm $i \in \{1, 2\}$ obtains a marginal production cost of c_{iR} for a sunk cost of F_i. If i does not undertake R&D, its unit production cost remains at its inital level of $c_{iN} > c_{iR}$. Therefore, in stage 1, firm i chooses between two combinations of marginal and sunk costs, $(c_{iN}, 0)$ and (c_{iR}, F_i), where the latter can be thought of as the installation of a new machine.[13] We assume that c_{iR} and c_{iN} are independent, so varying c_{iN} alters the *size* of the process innovation.[14]

In *stage two*, the duopolists compete à la Cournot on the market for a homogeneous

[11] In a similar vein, Eatwell (1982, pp. 76-7) describes the purposive promotion of major firms by the French Commissariat Général du Plan during the same period.

[12] By "linear," we mean linear demand and constant marginal cost.

[13] Note that this *discrete* formulation of the R&D decision is consistent with an underlying *continuous* R&D investment variable if the firm optimally chooses corners – e.g., if firm i chooses R&D investment level $x_i \in [0, 1]$, marginal cost equals $c_{iN} - (c_{iN} - c_{iR})\, x_i$, and R&D costs x_i.

[14] This assumption means that potential innovations are independent of the initial TFP dispersion in the industry.

good with inverse demand

$$p = 1 - (q_1 + q_2).$$

There are two principal justifications for our assumption of homogeneous products. First, given that we believe our qualitative insights will readily generalize to the case of differentiated products, it keeps our analysis mathematically straightforward.[15] Second, empirical evidence (Oulton, 1998) suggests that most of the variation across plants in total factor productivity (TFP) is within-industry, rather than between-industry. This is perhaps surprising, but it makes our assumption that producers of the same good face different R&D possibilities and costs plausible.[16]

We solve the game backwards to isolate its subgame perfect Nash equilibria in pure strategies. To avoid extensive and unrewarding taxonomy, we make two assumptions on the marginal cost parameters. First, we assume *nondrastic* process innovations.[17] This restricts the spread of marginal costs and requires

$$\frac{1}{2}(1 + c_{1R}) > c_{2N} \quad \text{and} \quad \frac{1}{2}(1 + c_{2R}) > c_{1N},$$

where the LHS's are monopoly prices following R&D, so the conditions ensure that either firm's monopoly price under R exceeds its rival's initial marginal cost. Second, we shall assume that $c_{2N} \geq c_{1N}$, so that, initially, 1 is the "major" firm and 2 the "minor" one. This assumption entails no loss of generality. It merely excludes cases that are distinguished only by firm labelling. We denote firm i's variable profits in Cournot equilibrium by $\pi(c_i, c_j)$, so

$$\pi(c_i, c_j) = \frac{1}{9}(1 - 2c_i + c_j)^2.$$

Using this notation, our game's payoff matrix is

[FIG. 1 HERE]

We shall define social welfare as the unweighted sum of profits and consumer surplus, which is given by

$$S(c_i + c_j) = \frac{1}{2}(q_1 + q_2)^2 = \frac{1}{18}(2 - (c_i + c_j))^2$$

[15] Although our qualitative results survive with differentiated products, *quantitatively* they will be weakened because a key mechanism behind our results is strategic substitution in the product market (but see also footnote 12).

[16] Moreover, the assumption of homogeneous goods facilitates straightforward comparison with the Lahiri/Ono (1988) analysis. Our qualitative results readily generalize to the case where $p = a - b(q_1 + q_2)$.

[17] i.e., that all four possible Cournot equilibria, one for each possible pair of marginal costs, are interior.

at an interior Cournot equilibrium. S is increasing and strictly convex in $(q_1 + q_2)$: a given rise in industry output (i.e. a given fall in p) is more valuable to consumers, the larger is the initial output that the price fall is spread over.

3 Analysis

Fig. 2 plots the game's perfect equilibria in (F_1, F_2)-space. The comparative statics are intuitive – increasing a firm's sunk cost of R&D makes it less likely to undertake R&D. The inter-regional boundaries are defined as follows:

$$\begin{aligned}
F_{1R}^* &= \pi(c_{1R}, c_{2R}) - \pi(c_{1N}, c_{2R}) = \frac{4}{9}(c_{1N} - c_{1R})[1 + c_{2R} - (c_{1N} + c_{1R})] \\
F_{1N}^* &= \pi(c_{1R}, c_{2N}) - \pi(c_{1N}, c_{2N}) = \frac{4}{9}(c_{1N} - c_{1R})[1 + c_{2N} - (c_{1N} + c_{1R})] \\
F_{2R}^* &= \pi(c_{2R}, c_{1R}) - \pi(c_{2N}, c_{1R}) = \frac{4}{9}(c_{2N} - c_{2R})[1 + c_{1R} - (c_{2N} + c_{2R})] \\
F_{2N}^* &= \pi(c_{2R}, c_{1N}) - \pi(c_{2N}, c_{1N}) = \frac{4}{9}(c_{2N} - c_{2R})[1 + c_{1N} - (c_{2N} + c_{2R})]
\end{aligned}$$

[FIG. 2 HERE]

F_{iR}^* (F_{iN}^*) is firm i's gain in variable profits from investing in R&D when its rival chooses R (N). $F_{iN}^* > F_{iR}^*$ because by investing in process R&D a firm's rival becomes a tougher competitor, which reduces the rent available on the product market to fund the firm's own R&D effort.[18] Note that we cannot in general say whether $F_{1R}^* \gtrless F_{2R}^*$ or $F_{1N}^* \gtrless F_{2N}^*$.[19]

We are interested in the normative effects of "helping" firm 2 by reducing c_{2N}. We start by ignoring the endogenous R&D aspect and focus on the (N, N) case. The industry's technology frontier is represented by c_{1N}, and policy can promote catch-up by reducing c_{2N} towards it. Social welfare is given by

$$W(N, N) = \pi(c_{1N}, c_{2N}) + \pi(c_{2N}, c_{1N}) + S(c_{1N} + c_{2N}).$$

The key point to note (Lahiri and Ono, 1988) is that $W(N, N)$ is *not* decreasing in c_{2N} on the whole interval of c_{2N} that is consistent with interior Cournot equilibria, i.e.

[18] Therefore, firm i's dominant strategy is R if $F_i < F_{iR}^*$ and N if $F_i > F_{iN}^*$. If $F_i \in [F_{iR}^*, F_{iN}^*]$, then i optimally chooses the opposite to its rival. In the central square in Fig. 2, we have a game of chicken where either firm prefers the equilibrium where it does the R&D.

[19] Two cases where ranking *is* possible deserve mention, however. First, if $c_{1R} = c_{2R}$ (i.e., R&D moves both firms onto the new technology frontier), then $F_{2R}^* > F_{1R}^*$ and $F_{2N}^* > F_{1N}^*$ for all $c_{2N} \in (c_{1N}, (1 + c_{1R})/2)$. Second, if $c_{1N} - c_{1R} = c_{2N} - c_{2R}$ (i.e., common innovation *size* across firms), then $F_{1R}^* > F_{2R}^*$ and $F_{1N}^* > F_{2N}^*$ for all $c_{2N} > c_{1N}$.

$c_{2N} \in \left(c_{1N}, \frac{1}{2}\left(1+c_{1N}\right)\right)$. In fact, $W(N,N)$ is U-shaped in c_{2N}.[20] If the gap $(c_{2N}-c_{1N})$ is sufficiently large, then *increasing* c_{2N} *increases* social welfare – or, equivalently, "helping minor firms reduces welfare." This result seems paradoxical, and it arises because the firms' outputs are strategic substitutes in our linear Cournot model. To see this, assume for the moment that q_1 is fixed and that market equilibrium is established by 2 acting as a monopolist on the residual demand curve. A rise in c_{2N} will lead to a fall in industry output (equal to the fall in q_2) and a fall in π_2. Moreover, society will be harmed because the loss to consumers exceeds the rise in π_1 (which is itself a transfer *from* consumers) since consumers face a higher price on *total* industry output. Strategic substitution in Cournot competition alters this story as follows: the rise in c_{2N} leads to a fall in industry output (and π_1, π_2, S all move in the same directions as before) *but* q_1 rises as q_2 falls – there is an efficient redistribution of inital production from firm 2 to firm 1. When $(c_{2N}-c_{1N})$ is sufficiently large, the welfare gain from redistributing production across firms is large enough to overturn our initial intuition.[21] [22] Therefore:

Proposition 1 (Lahiri and Ono, 1988): In a linear Cournot duopoly with both firms active in equilibrium, social welfare is U-shaped in the minor firm's marginal cost.

We characterize Proposition 1 as a *short run* result because it holds the firms' R&D policies fixed. In the *long run*, firms' R&D investments are variable, and we need to consider the effects of changing c_{2N} on R&D investment patterns. For any (F_1, F_2) in Fig. 2, reducing c_{2N} will shift inwards all the inter-regional boundaries except F_{1R}^*, which is independent of c_{2N}. The possibility therefore arises that, for given (F_1, F_2), cutting c_{2N} may alter equilibrium R&D decisions. F_{2R}^* and F_{2N}^* both fall when c_{2N} falls because the *size* of the process innovation that R&D investment grants firm 2 falls – recall that, by assumption, c_{2R} is independent of c_{2N}. F_{1R}^* is independent of c_{2N} because when 2 undertakes R&D, technology c_{2N} is eliminated from production. Finally, F_{1N}^* also

[20] See, for example, the plot of $W(N,N)$ in Fig. 4.

[21] $\pi_1+\pi_2$ is increasing in c_{2N} on $c_{2N} \in [(1+4c_{1N})/5, (1+c_{1N})/2]$. W is increasing in c_{2N} on $c_{2N} \in [(4+7c_{1N})/11, (1+c_{1N})/2]$, where $(4+7c_{1N})/11 > (1+4c_{1N})/5$ because S is uniformly falling in c_{2N}.

[22] Despite our focus on Cournot competition, we would obtain qualitatively identical results under Bertrand competition with differentiated products. In that case, helping the minor firm will push both firms' prices downwards (strategic complementarity), benefiting the minor firm and consumers but harming the major firm. However, the minor firm's *relative* price will also fall, which will cause an inefficient reallocation of initial production (major to minor). Likewise, Propositions 2 and 3 below will also generalize to Bertrand competition with differentiated products.

falls when c_{2N} falls. This reflects the fact that, with lower c_{2N}, 1's output is smaller in Cournot equilibrium for either of 1's R&D decisions. Therefore, the *value* of a given process innovation to 1, innovation size spread over equilibrium output, falls when c_{2N} falls.[23]

With endogenous R&D decisions, there are two cases to consider, "small" and "large" F_1. Formally, the distinction depends on whether $F_1 \gtrless F_{1R}^*$. Economically, it is the distinction between the case where 1 always undertakes R&D and that where 1's R&D decision is contingent on 2's.

3.1 Major firm's R&D is cheap: $F_1 < F_{1R}^*$

If $F_1 < F_{1R}^*$, which is independent of c_{2N}, then 1's dominant strategy is to invest in R&D. Therefore, there are two possible perfect equilibria (see Fig. 2): (R,R) for $F_2 < F_{2R}^*$, and (R,N) for $F_2 > F_{2R}^*$. The switchpoint, $F_{2R}^* = F_2$, occurs at[24]

$$c_{2N} = \alpha = \frac{1}{2}\left(1 + c_{1R} - 3\sqrt{\pi\left(c_{2R}, c_{1R}\right) - F_2}\right).$$

In words, if $c_{2N} = \alpha$, then firm 2 is indifferent between (R,R) and (R,N). If $c_{2N} > \alpha$, then 2 strictly prefers (R,R) to (R,N) and vice versa. Clearly, if $F_2 = 0$, then $\alpha = c_{2R}$; otherwise, $\alpha > c_{2R}$. By our assumptions on the marginal cost parameters, c_{2N} is restricted to the interval $\left(\max\left\{c_{1N}, c_{2R}\right\}, \frac{1}{2}\left(1 + c_{1R}\right)\right)$. In order to ensure that α always lies *within* this interval, we assume $F_2 < \pi\left(c_{2R}, c_{1R}\right)$, the value of F_{2R}^* when $\pi\left(c_{2N}, c_{1R}\right) = 0$ at $c_{2N} = \left(1 + c_{1R}\right)/2$.[25] Fig. 3 below plots social welfare in the two equilibria, $W\left(R,R\right)$ and $W\left(R,N\right)$, as functions of c_{2N}, where[26]

$$\begin{aligned} W\left(R,R\right) &= \pi\left(c_{1R}, c_{2R}\right) - F_1 + \pi\left(c_{2R}, c_{1R}\right) - F_2 + S\left(c_{1R} + c_{2R}\right) \\ W\left(R,N\right) &= \pi\left(c_{1R}, c_{2N}\right) - F_1 + \pi\left(c_{2N}, c_{1R}\right) + S\left(c_{1R} + c_{2N}\right) \end{aligned}$$

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[23] Our assumption of nondrastic process innovations is crucial for $\partial F_{1N}^*/\partial c_{2N} > 0$. If 1's innovation were *drastic*, we would get $\partial F_{1N}^*/\partial c_{2N} < 0$ because 1's profits in (R,N) would be independent of c_{2N}. Therefore, intensified competition weakens (strengthens) the incentive to invest in nondrastic (drastic) process innovations. This observation has implications for the impact of competition on chosen innovation *size* (drastic vs. nondrastic) and, perhaps, for the distinction between Schumpeter Mark I and II (Nelson and Winter, 1982; Breschi *et al.*, 2000).

[24] $F_{2R}^* = F_2$ yields a quadratic in c_{2N}, but only the smaller root is compatible with interior Cournot equilibria (the turning point of F_{2R}^* is at $c_{2N} = \left(1 + c_{1R}\right)/2$).

[25] For clarification, see the plot of critical F-values in the appendix.

[26] In Fig. 3, we set $c_{1R} = 0$ so the monopoly price $\left(1 + c_{1R}\right)/2 = 0.5$, $c_{1N} = 0.1$, and $c_{2R} = 0.15$. Therefore, $F_{1R}^* = 0.047 > F_1 = 0.025$, $\pi\left(c_{2R}, c_{1R}\right) = 0.054 > F_2 = 0.025$, and $\alpha = 0.24$.

[FIG. 3 HERE]

$W(R,R)$ is independent of c_{2N} because if 2 invests in R&D, technology c_{2N} is eliminated from production. $W(R,N)$ is U-shaped in c_{2N} for the reasons underlying Proposition 1. There are two key features of Fig. 3. First, $W(R,N) > W(R,R)$ whenever (R,N) is the equilibrium. This property is robust to changes in the cost parameters:[27]

Lemma 1: If $c_{2R} > c_{1R}$, then $W(R,N) > W(R,R)$ for all $c_{2N} \in [c_{2R}, \alpha]$ – i.e., whenever (R,N) is the unique perfect equilibrium given that $F_1 < F_{1R}^*$.

Proof: If $c_{2N} \leq \alpha$, then firm 2 prefers (R,N) to (R,R), so a *sufficient* condition for $W(R,N) > W(R,R)$ is $\pi(c_{1R}, c_{2N}) + S(c_{1R} + c_{2N}) > \pi(c_{1R}, c_{2R}) + S(c_{1R} + c_{2R})$. This condition ensures that the rest of society (i.e., firm 1 plus consumers) prefers (R,N). Iff $c_{2R} > c_{1R}$, then the sufficient condition holds for all $c_{2N} > c_{2R}$: LHS = RHS at $c_{2N} = c_{2R}$, and $\partial \text{LHS}/\partial c_{2N} > 0$ for all $c_{2N} > c_{1R}$.

In particular, Lemma 1 means that $W(R,N) > W(R,R)$ at $c_{2N} = \alpha$ where 2 is indifferent between R and N, so there is a jump upwards in social welfare when c_{2N} is pushed below α. This property is purely driven by the welfare effects on the rest of society (because firm 2 is indifferent), and it arises because of the strategic substitution in Cournot equilibrium and consequent *efficient* redistribution of intial production levels caused by a rise in 2's marginal cost from c_{2R} to c_{2N} when 2 abandons R&D (as in Proposition 1).

The second noteworthy feature of Fig. 3 is an artefect of the chosen cost parameters: the switchpoint α lies to the left of the turning point of $W(R,N)$, which implies that "helping" firm 2 *always* increases social welfare. Specifically, this second property requires that F_2 be sufficiently small. To understand this, note that the curvature of a given $W(\cdot,\cdot)$ function is independent of the sunk costs F_1, F_2 because they enter social welfare additively. However, the switchpoints between different R&D regimes in equilibrium *do* vary with the sunk costs of R&D. Therefore, by increasing F_2 we would weaken 2's R&D incentive and eventually push α to the right of the turning point in $W(R,N)$ (see also the appendix figure). Proposition 2 sums up our results:

[27] The condition $c_{2R} > c_{1R}$ means that the laggard cannot leap-frog over the leader if the leader invests in R&D. Given the large within-industry variation in TFP across firms typically observed in the data, this seems plausible.

Proposition 2: In a linear Cournot duopoly with nondrastic process innovations where the major firm always invests in R&D, helping the minor firm increases social welfare discretely if it prompts the minor firm to abandon its R&D plans. Moreover, if the minor firm's R&D is sufficiently cheap, then helping it *always* increases social welfare in the long run.

It is useful to reflect on the mechanism behind Proposition 2. If it causes the minor firm to abandon its R&D plans, then *reducing* the initial (ex ante) productivity gap between the firms by cutting c_{2N} raises equilibrium social welfare discretely because it *widens* the equilibrium (ex post*)* productivity gap and thereby provokes an efficient reallocation of initial production levels.

Overall, this section has achieved two things. First, in cases where the firms' R&D decisions are unchanging so social welfare varies continuously with the minor firm's marginal cost, we have weakened the Lahiri/Ono result on the conditions under which "helping" the minor firm is harmful. Social welfare can increase in the minor firm's marginal cost only if its sunk cost of R&D (and therefore α) is sufficiently large. Second, we have shown that helping firm 2 causes a jump upwards in social welfare at the point where 2 shelves its R&D plans as firm 1 grows at the expense of 2 on the product market. In the next section we consider the case of costly major-firm R&D.

3.2 Major firm's R&D is costly: $F_1 > F_{1R}^*$

If $F_1 > F_{1R}^*$, then there are three possible perfect equilibria: (N, R), (R, N), and (N, N). We begin by tying down the equilibria at the extremes, $c_{2N} = c_{2R}$ and $c_{2N} = (1 + c_{1R})/2$, 1's monopoly price following R&D. For any (F_1, F_2) with $F_1 > F_{1R}^*$, the perfect equilibrium when $c_{2N} = c_{2R}$ is (N, N).[28] (We shall assume throughout this section that $c_{2R} > c_{1N}$, so the constraint $c_{2N} > c_{1N}$ never bites.[29]) At the top end, where $c_{2N} = (1 + c_{1R})/2$, so 2 is pushed out of the market if 1 innovates alone, we shall assume $F_{1N}^* > F_1$ and $F_{2R}^* > F_2$

[28] Of course, if $c_{2N} = c_{2R}$, then $F_{1N}^* = F_{1R}^*$ and $F_{2N}^* = F_{2R}^* = 0$ – 1's incentive to innovate is independent of 2's choice, and 2 has no incentive to invest in R&D.

[29] $c_{2R} > c_{1N}$ rules out leap-frogging (whether or not the leader undertakes R&D) – laggards must first catch up with leaders before overtaking them. It seems a sensible assumption given the very large within-industry variation in TFP across firms that is typically observed in the data (Haskel and Martin, 2002). It implies that 1's R&D activity is *innovative*, having the effect of moving the industry's technology frontier outwards, whereas 2's is purely *imitative*, concerned only with catch-up. (2's R&D activity would combine both types if $c_{1N} > c_{2R}$.)

so the perfect equilibrium is (N, R) (see Fig. 2).[30]

Starting at $c_{2N} = (1 + c_{1R})/2$ with an equilibrium of (N, R), "helping" firm 2 shifts F^*_{1N}, F^*_{2R} and F^*_{2N} all inwards as the returns to innovation fall. Developing the notation from the previous section, we define two critical levels of c_{2N} to make firm 2 indifferent between N and R:

$$\begin{aligned} F^*_{2R} &= F_2 \text{ at } c_{2N} = \alpha = \frac{1}{2}\left(1 + c_{1R} - 3\sqrt{\pi(c_{2R}, c_{1R}) - F_2}\right) \\ F^*_{2N} &= F_2 \text{ at } c_{2N} = \beta = \frac{1}{2}\left(1 + c_{1N} - 3\sqrt{\pi(c_{2R}, c_{1N}) - F_2}\right) \end{aligned}$$

where (see plot in appendix)

$$\frac{1}{2}(1 + c_{1R}) \underbrace{>}_{\mathrm{I}} \alpha \underbrace{>}_{\mathrm{II}} \beta \underbrace{>}_{\mathrm{III}} c_{2R}.$$

α was defined above. In similar manner, if $c_{2N} > \beta$, then firm 2 strictly prefers (N, R) to (N, N) and vice versa. The sequence of perfect equilibria as c_{2N} falls from $(1 + c_{1R})/2$ to c_{2R} depends on which interval (I, II or III) a third critical level of c_{2N}, γ, occupies. At $c_{2N} = \gamma$, $F^*_{1N} = F_1$ and firm 1 is indifferent between (R, N) and (N, N). Therefore,

$$\gamma = \frac{9F_1}{4(c_{1N} - c_{1R})} + c_{1N} + c_{1R} - 1.$$

As c_{2N} falls, there are three possible sequences of equilibria to consider (see plot in appendix):[31]

$$\begin{aligned} \text{Sequence I } (\gamma > \alpha > \beta) &: (N, R) \underset{\beta}{\rightarrow} (N, N) \\ \text{Sequence II } (\alpha > \gamma > \beta) &: (N, R) \underset{\alpha}{\rightarrow} \{(R, N) \text{ or } (N, R)\} \underset{\gamma}{\rightarrow} (N, R) \underset{\beta}{\rightarrow} (N, N) \\ \text{Sequence III } (\alpha > \beta > \gamma) &: (N, R) \underset{\alpha}{\rightarrow} \{(R, N) \text{ or } (N, R)\} \underset{\beta}{\rightarrow} (R, N) \underset{\gamma}{\rightarrow} (N, N) \end{aligned}$$

In each sequence, the labels below the arrows indicate the switchpoints. Think of sequences I, II and III as corresponding to large, intermediate and small F_1/F_2 respectively (i.e., different *relative* R&D costs). Qualitatively, sequence I is identical to the analysis of the previous section, and the observations summed up in Proposition 2 all apply (see Lemma 2(a) for a proof that equilibrium social welfare jumps upwards at $c_{2N} = \beta$). The only difference is that 1 always chooses N, rather than R.

[30] The cases where, for any subscripts, $F > F^*$ for all permissible c_{2N} represent subsets of our results.

[31] If one imagines Fig. 2 as dividing (F_1, F_2)-space into 9 cells using the solid and dashed lines, then each sequence corresponds to a different path from the middle cell in the bottom row to the top right cell.

Fig. 4 plots equilibrium social welfare in sequence III, the only sequence where all three possible equilibria exist uniquely. (As Lemmas 2 and 3 below show, equilibrium social welfare in sequence II is higher under (R, N) than under (N, R) when there are two equilibria, as in sequence III, and it jumps upwards when c_{2N} falls below β, as in sequence I.)

[FIG. 4 HERE]

Lemma 2 shows that two features of Fig. 4, $W(N, N) > W(N, R)$ at $c_{2N} = \beta$ and $W(R, N) > W(N, N)$ at $c_{2N} = \gamma$, are quite general:

Lemma 2: (a) If $c_{2R} > c_{1N}$, then $W(N, N) > W(N, R)$ for all $c_{2N} \in [c_{2R}, \beta]$ – i.e., whenever (N, N) is the unique perfect equilibrium given that $F_1 > F^*_{1R}$. (b) Given that $c_{1N} \in (c_{1R}, c_{2N}]$, $W(R, N) > W(N, N)$ for all $c_{2N} \in [\gamma, (1 + c_{1R})/2]$ – i.e., whenever (R, N) is a perfect equilibrium given that $F_1 > F^*_{1R}$.

Proof: (a) If $c_{2N} \leq \beta$, then firm 2 prefers (N, N) to (N, R), so a *sufficient* condition for $W(N, N) > W(N, R)$ is $\pi(c_{1N}, c_{2N}) + S(c_{1N} + c_{2N}) > \pi(c_{1N}, c_{2R}) + S(c_{1N} + c_{2R})$. This condition ensures that the rest of society (i.e., firm 1 plus consumers) prefers (N, N). Iff $c_{2R} > c_{1N}$, then the sufficient condition holds for all $c_{2N} > c_{2R}$: LHS = RHS at $c_{2N} = c_{2R}$, and $\partial\text{LHS}/\partial c_{2N} > 0$ for all $c_{2N} > c_{1N}$. (b) If $c_{2N} \geq \gamma$, then firm 1 prefers (R, N) to (N, N), so a *sufficient* condition for $W(R, N) > W(N, N)$ is $\pi(c_{2N}, c_{1R}) + S(c_{1R} + c_{2N}) > \pi(c_{2N}, c_{1N}) + S(c_{1N} + c_{2N})$. This condition ensures that the rest of society (i.e., firm 2 plus consumers) prefers (R, N). Given that $c_{1N} \in (c_{1R}, c_{2N}]$, the sufficient condition holds: LHS = RHS at $c_{1N} = c_{1R}$, and $\partial\text{RHS}/\partial c_{1N} < 0$ for all $c_{1N} < c_{2N}$.

In particular, Lemma 2(a) shows that the transition from (N, R) to (N, N) in sequences I and II, which occurs at $c_{2N} = \beta$, is associated with an upwards jump in social welfare. This might seem paradoxical because the sum of marginal costs rises. The welfare change is the effect on firm 1 plus consumers of an increase in firm 2's marginal cost from c_{2R} to c_{2N} (firm 2, the "minor" firm, is itself indifferent between (N, R) and (N, N) at $c_{2N} = \beta$). The jump arises because of strategic substitution on the product market – firm 1 expands at the expense of 2 when 2's marginal cost rises, which cuts production costs on the redistributed output. The same mechanism of strategic substitution, although working in the opposite direction, contributes to the result in Lemma 2(b). In sequence III, the transition from (R, N) to (N, N) at $c_{2N} = \gamma$ is associated with a jump downwards in social welfare. The rise in 1's marginal cost from c_{1R} to c_{1N} would harm the rest of society at initial production levels. Strategic substitution on the product market strengthens this negative effect – 2 grows at the expense of 1 when 1 switches from R to N, which is an inefficient redistribution of initial production.

In all three welfare comparisons in Lemmas 1 and 2, only *one* firm alters its R&D policy between the outcomes compared. Consequently, both Lemmas use the same method of proof. On the space where the firm whose R&D policy alters has a best response in favour of a given outcome, we define a *sufficient* condition for ranking social welfare in the two outcomes, which is based on the preference of the rest of society (i.e., consumers plus the firm with unchanged R&D decision). Moreover, in both Lemmas, we isolate conditions under which the outcome that *maximizes Firm 1's R&D spending lead* (over 2) is welfare-superior.

Lemma 3 differs from the previous two because *both* firms' R&D policies change across the outcomes compared, (R, N) and (N, R). Therefore, the method of proof also differs. In moving between the equilibria (R, N) and (N, R), we certainly know that the firm that takes up (abandons) R&D gains (loses). The effect on consumers is unclear, depending on whether $c_{1R} + c_{2N} \gtrless c_{1N} + c_{2R}$, which determines the price change. Lemma 3 aggregates these effects:[32]

Lemma 3: If $c_{2R} > c_{1N} + (c_{1N} - c_{1R})/3$, then $W(R, N) > W(N, R)$ for all $c_{2N} \in [\gamma, \alpha]$ – i.e., whenever (R, N) is a perfect equilibrium given that $F_1 > F^*_{1R}$.

Proof: $c_{2N} \geq \gamma$ is equivalent to $F_1 \leq F^*_{1N}$, and $c_{2N} \leq \alpha$ is equivalent to $F_2 \geq F^*_{2R}$. Therefore, by substituting F^*_{1N}, F^*_{2R} for F_1, F_2 in $W(R, N) > W(N, R)$, we obtain a *sufficient* condition for $W(R, N) > W(N, R)$ on $c_{2N} \in [\gamma, \alpha]$: $\pi(c_{1N}, c_{2N}) + S(c_{1R} + c_{2N}) > \pi(c_{1N}, c_{2R}) + \pi(c_{2R}, c_{1N}) - \pi(c_{2R}, c_{1R}) + S(c_{1N} + c_{2R})$. The RHS is independent of c_{2N}, and $\partial\text{LHS}/\partial c_{2N} > 0$ for all $c_{2N} > c_{2R}$ iff $c_{2R} > c_{1N} + (c_{1N} - c_{1R})/3$. At $c_{2N} = c_{2R}$, the sufficient condition holds iff $\pi(c_{2R}, c_{1R}) + S(c_{1R} + c_{2R}) > \pi(c_{2R}, c_{1N}) + S(c_{1N} + c_{2R})$. This second condition holds for all $c_{1N} \in (c_{1R}, c_{2R}]$: LHS = RHS at $c_{1N} = c_{1R}$, and $\partial\text{RHS}/\partial c_{1N} < 0$ for all $c_{1N} < c_{2R}$.

[32] The condition $c_{2R} > c_{1N} + (c_{1N} - c_{1R})/3$ is more demanding than our "no leap-frogging" condition $c_{2R} > c_{1N}$. The two converge as the size of 1's process innovation tends towards 0.

Taken together, Lemmas 1, 2(b) and 3 imply that *whenever* (R, N) arises in equilibrium, it is associated with higher social welfare than the other three outcomes.[33] [34] Strategic substitution plays a role in Lemma 3. To highlight it, consider the special case where $F_1 = F_2$ and the innovation *size* is common across firms ($\Rightarrow c_{1R}+c_{2N} = c_{1N}+c_{2R}$).[35] Together, these assumptions mean that the welfare comparison of (R, N) and (N, R) depends only on industry variable profits in the two cases. The common innovation size assumption means that industry output and price (and, therefore, consumer surplus and revenue) are the same in both cases. Therefore, $W(R, N) > W(N, R)$ if and only if $\pi(c_{1R}, c_{2N}) + \pi(c_{2N}, c_{1R}) > \pi(c_{1N}, c_{2R}) + \pi(c_{2R}, c_{1N})$. Given our assumed ranking $c_{2N} > c_{2R} > c_{1N} > c_{1R}$, strategic substitution means that this condition holds because the spread of marginal costs is greater in (R, N) (Salant and Shaffer, 1999).[36]

Taking the results of the previous section and this one together, there are five distinct transitions between equilibria that can be caused by helping firm 2. With "small" F_1, the transition is $(R, R) \to (R, N)$. With "large" F_1, the transition in sequence I is $(N, R) \to (N, N)$; sequence II adds the potential transitions $(N, R) \to (R, N) \to (N, R)$;[37] finally, sequence III adds $(R, N) \to (N, N)$. Proposition 3 sums up the preceding analysis and summarises the normative effects of these transitions between equilibria:

Proposition 3: In a linear Cournot duopoly with nondrastic process innovations, where the firms' cost structures are asymmetric, helping the minor firm causes social welfare to jump upwards (downwards) if it increases (decreases) the major firm's R&D spending lead over the minor firm.

[33] (R, N) is an equilibrium if $F_1 \leq F_{1N}^*$ and $F_2 \geq F_{2R}^*$, i.e. $c_{2N} \in [\gamma, \alpha]$.

[34] This finding is reminiscent of Result 2 in Mills and Smith (1996), who show in a completely symmetric game of R&D competition in Cournot duopoly (i.e., $c_{1N} = c_{2N} > c_{1R} = c_{2R}$ and $F_1 = F_2$ in our model) that if an asymmetric "chicken" equilibrium exists (i.e., only one firm does R&D), it is the welfare-optimal outcome. Of course, as in our analysis, this is only "second best" welfare optimality because Cournot competition on the product market is taken for granted. (However, for criticism of the robustness of the duopoly assumption in Mills/Smith, see Elberfeld, 2003.)

[35] For this demonstration, we could let $F_1 < F_2$, but then our condition for $W(R, N) > W(N, R)$ would be only sufficient.

[36] The common innovation size assumption ($c_{iN} - c_{iR} = \delta > 0$) means that industry revenue is the same in (R, N) and (N, R). Therefore, given $F_1 = F_2$, $W(R, N) > W(N, R)$ if and only if industry production costs are lower in (R, N). This requires $c_{1R}q_1^R + (c_{2R} + \delta)\left(\overline{Q} - q_1^R\right) < (c_{1R} + \delta)\, q_1^N + c_{2R}\left(\overline{Q} - q_1^N\right)$, where q_1^R and q_1^N are 1's equilibrium outputs in (R, N) and (N, R) respectively, and $\overline{Q}$ is the common level of industry output. Simplifying, the inequality becomes $q_1^R + q_1^N > \overline{Q}$, which holds given $c_{2R} > c_{1N}$ because $q_1^R > q_1^N > \overline{Q}/2$.

[37] If (N, R) is selected in the central "chicken" area of Fig. 2, then these two transitions do not arise in sequence II.

In Proposition 3, the major (large) firm is 1, and the minor (small) one is 2. Firm i's spending on R&D belongs to $\{0, F_i\}$, depending on whether i undertakes R&D. Firm 1's *R&D spending lead* is its spending on R&D minus firm 2's.

In addition to the discrete changes in social welfare that occur when helping firm 2 changes equilibrium R&D choices, there are also continuous changes in social welfare when equilibrium R&D policies remain unchanged. Social welfare in (N, R) is independent of c_{2N} because 2's marginal cost is c_{2R}. Social welfare in both (R, N) and (N, N) is U-shaped in c_{2N} for the reasons behind Proposition 1. As in the previous section, the curvature of a given $W(\cdot, \cdot)$ function is independent of the sunk costs F_1, F_2, but the switchpoints between different R&D regimes in equilibrium *do* vary with the sunk costs of R&D. Also as previously, by setting α "sufficiently small" we can ensure that helping firm 2 always increases social welfare when equilibrium R&D choices are fixed because a *necessary* condition for firm 2 to choose N is $c_{2N} < \alpha$. Of course, α "small" requires F_2 "small," which is intuitive: by setting F_2 sufficiently small, we increase firm 2's willingness to invest in R&D and push the switchpoint where (N, R) ceases to be a unique equilibrium to the left of the turning points in $W(R, N)$ and $W(N, N)$.

Proposition 3 generalizes Proposition 2 to show that *any* slight narrowing of the initial (ex ante) productivity gap between the firms, $c_{2N} - c_{1N}$, that leads to a widening of the equilibrium (ex post) productivity gap, by causing firm 1's R&D spending lead over firm 2 to rise, raises social welfare discretely. We have also uncovered an additional *mechanism* through which helping firm 2 can increase 1's R&D spending lead and social welfare. In the last section, firm 1 always undertook R&D, and the mechanism was that helping firm 2 caused it to abandon R&D. In this section, we have shown that helping firm 2 can cause *both* firms to change R&D actions. For example, assume in sequence III that whenever (R, N) and (N, R) both exist as equilibria, (N, R) is played. Then, when c_{2N} is pushed below β, the equilibrium changes from (N, R) to (R, N), which produces a larger jump in social welfare than the transition $(N, R) \to (N, N)$. Pushing c_{2N} below β makes N a dominant strategy for firm 2 and , in response, firm 1 takes up its R&D plans.

4 Conclusion

We have analysed the welfare effects of productivity catch-up by a minor firm in a duopoly. The catch-up takes the form of a narrowing of the initial marginal-cost gap between the firms. In the short run, where the firms' process technologies are fixed, "helping" the minor firm produces the Lahiri/Ono (1988) result. If the initial productivity gap is sufficiently large, then reducing the minor firm's marginal cost causes social welfare to fall because it causes a socially inefficient reallocation (i.e., major-to-minor) of initial production.

In the long run, the firms' process R&D investments are endogenously determined to maximize profits. If "helping" the minor firm causes the major firm's R&D spending lead over its rival to grow (through changes in R&D investment patterns), then social welfare jumps upwards. By extending the major firm's R&D spending lead, reducing the initial productivity gap between the firms raises social welfare discretely because it widens the equilibrium productivity gap. This widening provokes a socially efficient reallocation (i.e., minor-to-major) of initial production levels.

Although our quantitative results are derived using a rather stylized model, we believe that our qualitative insights will survive in more general contexts – e.g., for a broad class of cost/demand functions, and under Bertrand competition on the product market. The key mechanism behind our results is that "helping" the minor firm causes it to steal business from the major firm in product-market equilibrium, and this is a standard characteristic of oligopoly models. Given this expectation, our findings are most clearly illustrated using a simple model.

References

Boone, J. (2001), "Intensity of competition and the incentive to innovate," *International Journal of Industrial Organization*, 19, pp. 705-26.

Brander, J. A., and Spencer, B. J. (1983), "Strategic commitment with R&D: the symmetric case," *Bell Journal of Economics*, 14(1), pp. 225-35.

Breschi, S., Malerba, F., and Orsenigo, L. (2000), "Technological regimes and Schumpeterian patterns of innovation," *Economic Journal*, 110, pp. 388-410.

d'Aspremont, C., and Jacquemin, A. (1988), "Cooperative and noncooperative R&D in duopoly with spillovers," *American Economic Review,* 78(5), pp. 1133-37.

DTI (2001), *Productivity and Enterprise: A World Class Competition Regime*, London: Department of Trade and Industry, Cm 5233.

Dwyer, D. W. (1998), "Technology locks, creative destruction, and nonconvergence in productivity levels," *Review of Economic Dynamics*, 1(2), pp. 430-73.

Eatwell, J. (1982), *Whatever happened to Britain?* London: Duckworth.

Elberfeld, W. (2003), "A note on technology choice, firm heterogeneity and welfare," *International Journal of Industrial Organization*, 21, pp. 593-605.

Ferrett, B. (2005), "Foreign direct investment and productivity growth: theory," in H. Görg, D. Greenaway, and R. Kneller, eds., *Globalisation and Productivity Growth: Theory and Evidence*, Palgrave Macmillan.

Ferrett, B. (2006), "Productivity distributions in international oligopolies: spillovers, technology transfer, and heterogeneous FDI", GEP Research Paper 2006/02, School of Economics: Nottingham University.

Görg, H., and Greenaway, D. (2004), "Much ado about nothing? Do domestic firms really benefit from foreign direct investment?", *World Bank Research Observer*, 19(2), pp. 171-97.

Griffith, R., Redding, S., and Simpson, H. (2004), "Foreign ownership and productivity: new evidence from the service sector and the R&D lab", IFS Working Paper No. 04/22, Institute for Fiscal Studies: London.

Haskel, J., and Martin, R. (2002), "The UK manufacturing productivity spread," CeRiBA Discussion Paper, Office for National Statistics: London.

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

Lahiri, S., and Ono, Y. (1988), "Helping minor firms reduces welfare," *Economic Journal*, 98, pp. 1199-1202.

Leahy, D., and Neary, J. P. (1997), "Public policy towards R&D in oligopolistic industries," *American Economic Review*, 87(4), pp. 642-62.

Malerba, F. (1992), "Learning by firms and incremental technical change," *Economic Journal*, 102, pp. 845-59.

Mills, D. E., and Smith, W. (1996), "It pays to be different: Endogenous heterogeneity of firms in an oligopoly," *International Journal of Industrial Organization*, 14, pp. 317-29.

Nelson, R., and Winter, S. (1982), *An Evolutionary Theory of Economic Change.* Cambridge, Mass.: Harvard University Press.

Oulton, N. (1998), "Competition and the dispersion of labour productivity amongst UK companies," *Oxford Economic Papers*, 50(1), pp. 23-38.

Qiu, L. D. (1997), "On the dynamic efficiency of Bertrand and Cournot equilibria," *Journal of Economic Theory*, 75(1), pp. 213-29.

Röller, L.-H., and Sinclair-Desgagné, B. (1996), "On the heterogeneity of firms," *European Economic Review*, 40, pp. 531-39.

Salant, S. W., and Shaffer, G. (1999), "Unequal treatment of identical agents in Cournot equilibrium," *American Economic Review*, 89(3), pp. 585-604.

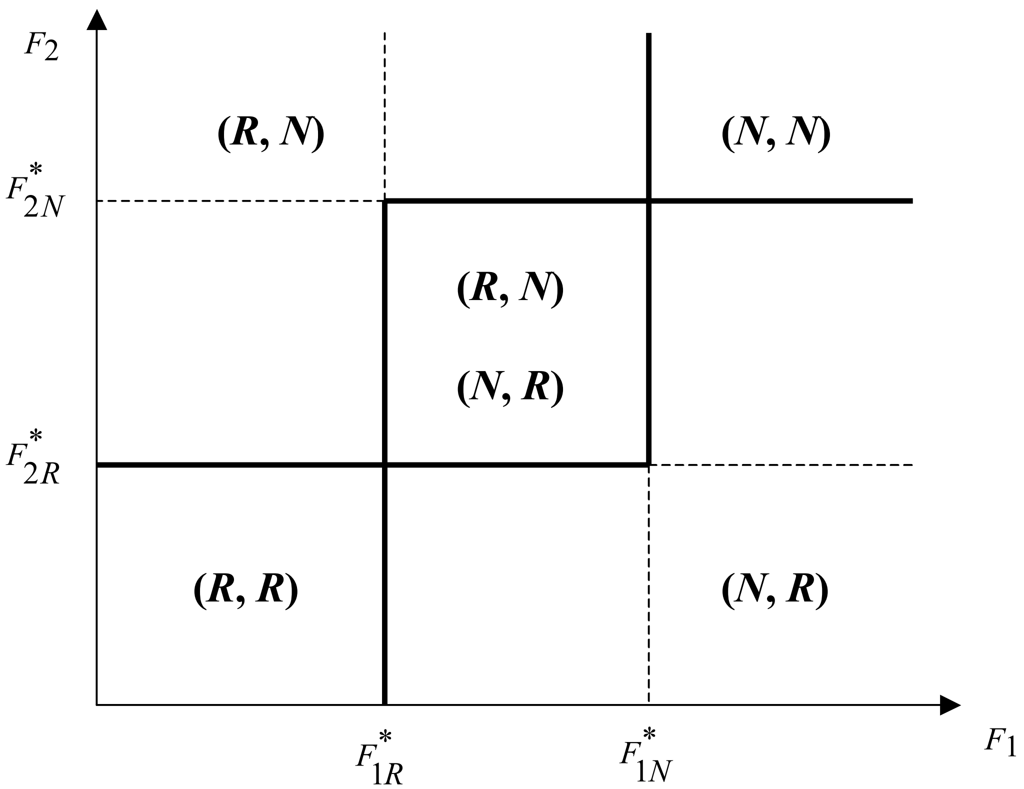
Suzumura, K. (1992), "Cooperative and noncooperative R&D in an oligopoly with spillovers," *American Economic Review*, 82(5), pp. 1307-20.

Tandon, P. (1984), "Innovation, market structure, and welfare," *American Economic Review*, 74(3), pp. 394-403.

Zhao, J. (2001), “A characterization for the negative welfare effects of cost reduction in Cournot oligopoly,” *International Journal of Industrial Organization*, 19, pp. 455-69.

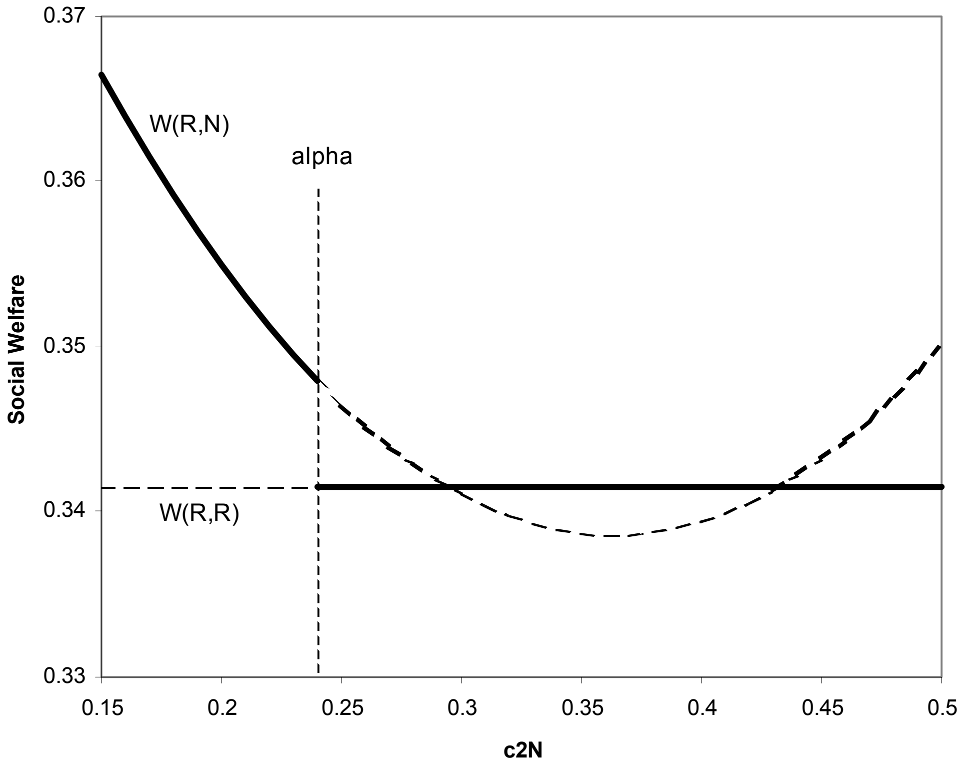
		Firm 2	
		N	***R***
Firm 1	***N***	$\pi(c_{2N},c_{1N})$ $\pi(c_{1N},c_{2N})$	$\pi(c_{2R},c_{1N})-F_2$ $\pi(c_{1N},c_{2R})$
	R	$\pi(c_{2N},c_{1R})$ $\pi(c_{1R},c_{2N})-F_1$	$\pi(c_{2R},c_{1R})-F_2$ $\pi(c_{1R},c_{2R})-F_1$

(Above) **Figure 1: Payoff Matrix**



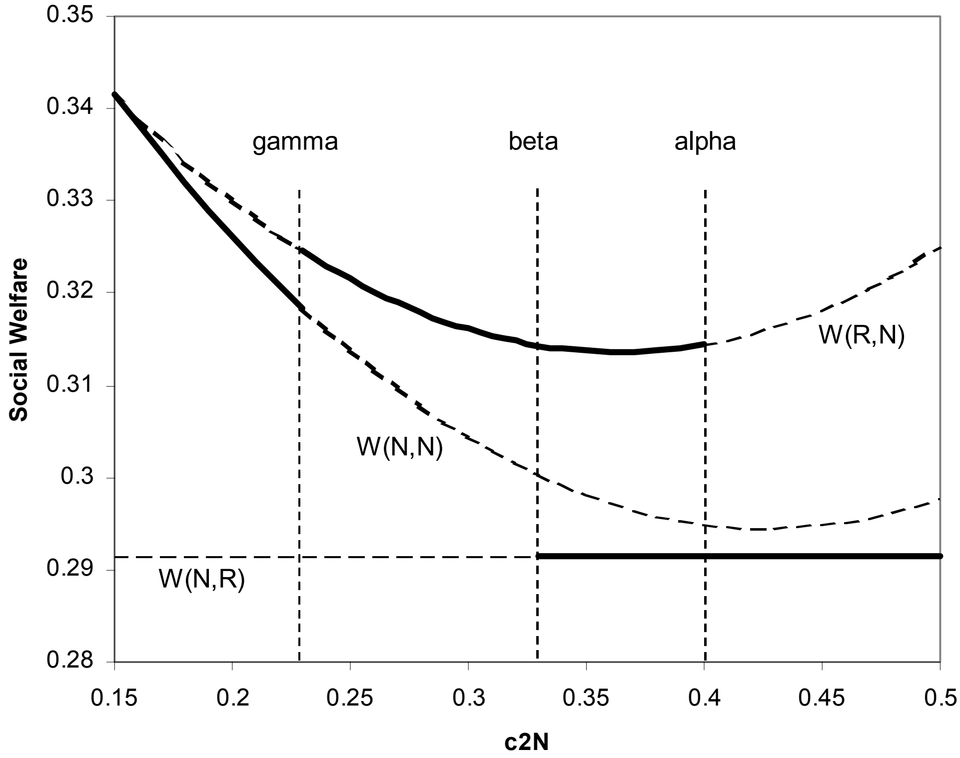
(Above) **Figure 2: Perfect Equilibria in R&D Cost Space**

Notes: F^*_{1R} is independent of c_{2N}. $F_1 = F^*_{1N}$ is equivalent to $c_{2N} = \gamma$. $F_2 = F^*_{2R}$ ($F_2 = F^*_{2N}$) is equivalent to $c_{2N} = \alpha$ (β).



(Above) **Figure 3: Equilibrium Social Welfare if Major Firm's R&D is Cheap**

Notes: Equilibrium social welfare is the **solid bold** line. Parameter values: c1N = 0.1, c1R = 0, c2R = 0.15, F1 = F2 = 0.025; so $\alpha \cong 0.24$.



(Above) **Figure 4: Equilibrium Social Welfare if Major Firm's R&D is Costly**

Notes: Equilibrium social welfare is the **solid bold** line. Parameter values: c1N = 0.1, c1R = 0, c2R = 0.15, F1 = F2 = 0.05; so $\alpha = 0.4$, $\beta \cong 0.33$, $\gamma \cong 0.23$.

Appendix Figure: Critical *F*-values and the Determination of α, β and γ

Note: This figure illustrates sequence I from section 3.2 ($\gamma > \alpha > \beta$).