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# Does Foreign R&D Competition Promote Domestic R&D?

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What type of competition policy is best suited to promote growth in knowledge intensive industries of small countries? Does competition stimulate growth through lower costs and more innovations, or does it mainly lead to wasteful duplication of R&D? Since innovations are motivated by expectations of future monopoly profits, then why not accept attempts at concentration and stimulate interfirm cooperation on R&D?

Recently, Nickell (1996) and Nickell et al. (1997) have presented some new empirical evidence in disfavour of this viewpoint: Using data on UK manufacturing, they find a significant positive effect of competition on total factor productivity growth. While this would seem to call for traditional anti-trust policy measures, industry leaders in small open economies like the Nordic ones might reasonably claim that they get more than enough competition from abroad. However, in his study of internationally successful industries in 10 countries, Porter (1990) reports that "Among the strongest empirical findings of our research is the association between vigorous domestic rivalry and the creation and persistance of competitive advantage in an industry. [] Nations with leading world positions often have a number of strong local rivals, even in small countries like Sweden or Switzerland"[1].

This finding is consistent with endogeneous growth theory (Romer 1986, Grossman and Helpman 1991), which emphasizes positive externalities from knowledge spillovers among related firms in the same country, and limited possibilities for foreign firms to benefit from such spillovers. In such a framework, an increase in the number of domestic firms will increase domestic innovation and knowledge spillovers. However, this is not primarily a story about competition driving innovation and growth, but rather one of positive feedback between knowledge and innovation which could as

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1. Porter (1990) p. 117.

well take place in a concentrated industry, or even within a single firm.

One may then argue, as Porter (1990) does, that knowledge based competitive advantage is short-lived, and therefore only sustainable through heavy investments in R&D, but that firms who achieve a technological edge over their competitors will tend to be more concerned with exploiting their current monopoly position than to preserve their technological leadership. This view is supported by Reinganum (1985), who uses a dynamic version of Lee and Wilde's (1980) patent race model to show that an incumbent firm will typically invest less in R&D than its competitors. It implies that "national champions" will tend to lose their technological leadership to foreign competitors from time to time. However, such would be the fate of any technologically leading firm, no matter whether it faces predominantly domestic or foreign competition. So why would domestic rivalry be superior to rivalry with foreign firms in terms of stimulating domestic firms to innovate more?

In this paper, we suggest a new mechanism that yields this result, and where the basic idea is as follows: Consider an R&D intensive industry consisting of regional agglomerations of firms in different countries. Some agglomerations consist of more firms than others, and they will therefore on average produce more innovations than small ones. Suppose that firms have access to information networks which are tighter locally than globally, meaning that information about new ideas, technologies and products spreads faster within agglomerations than between them. Firms in large agglomerations will therefore be better informed about the location of the research frontier than firms in small agglomerations, because more innovations will be made by other firms within their own local network. This *information externality* will give them a better position to evaluate the expected profitability of R&D projects, and in particular to stay away from projects which are doomed to fail because some competitor has already hit upon the right idea of how to solve that particular research problem. Firms in large agglomerations will therefore on average spend less R&D effort per innovation than firms in small agglomerations, and this cost advantage may cause them to grow even larger over time as firms find it in their interest to relocate their activities to larger agglomerations in order to benefit from their cost advantages.

Note that the basic idea behind this mechanism is quite similar to that of endogeneous growth theory, where spillovers of nonexcludable knowledge create positive externalities among firms in the same region[2]. The difference is that in our case, a similar type of externality arises even if knowledge is a perfectly excludable good[3]. For our mechanism to work, it is only necessary that firms are better informed about the R&D achievements of other firms in their own local network than those of firms in other local networks. For the sake of intuition, think of agglomerations of firms as universities and their faculty, and consider the hypothetical situation of being located in the outskirts of the academic community when an incoming discussion paper arrives which proves exactly the point one tried to make during the last

2. See e.g. Grossman and Helpman (1990) ch. 8.
3. The empirical results of Zucker et al. (1994) indicate that this is actually a good description in some cases, notably in the California biotech industry, where variations in rates of innovation can be accounted for by variations in the amount of market based knowledge exchange only.

few months. It is this risk of reinventing the wheel which drives the mechanism that we suggest here, and the question then is whether the local information networks which form the basis for it are likely to exist in practice.

Recent empirical research indicates that informal local networks are a key to understanding the formation of regional agglomerations in knowledge intensive industries. Powell et al. (1996) provide evidence from the biotech industry which supports their hypothesis that in such industries, "the locus of innovation will be found in networks of learning, rather than in individual firms"[4]. And in a comparative study of the electronics industries in Silicon Valley and Route 128, Saxenian (1994) describes these networks as being extremely localized and informal. For example, "The Wagon Wheel Bar in Mountain View, a popular watering hole where engineers met to exchange ideas and gossip has been termed 'the fountainhead of the semiconductor industry'. [] By all accounts, these informal conversations were pervasive and served as an important source of up-to-date information about competitors, customers, markets and technologies."[5] A number of authors have presented empirical evidence which supports the hypothesis that the benefits of such networks are mainly local in scope[6]. For example, using data on patents and patent citations for the US, Jaffe et al. (1993) find that "citations to domestic patents are more likely to be domestic, and more likely to come from the same state and the same [metropolitan area] as the cited patents, compared with a 'control frequency' reflecting the pre-existing concentration of related research activity"[7].

In order to model information exchange in networks, we begin with the standard assumption from endogeneous growth theory, that information about new technologies and products spreads faster locally than globally. However, in order to focus strictly on the role of competition, we disregard accumulated knowledge as a productive input to the innovation process, and let knowledge spillovers among firms be limited to information about the outcomes of the R&D activities of competing firms. As our point of departure, we therefore take Lee and Wilde's (1980) model of a patent race, where the R&D technology is memoryless and nothing is learned by any firm until one of them has eventually solved the whole research problem. Thus no knowledge is accumulated along the way to a solution, and so there are no benefits to reap from local knowledge spillovers among firms in a country with many competitors. We build a two-country version of Lee and Wilde's model, and represent differences between the efficiency of local and global information networks in the simplest possible manner: If a firm in one country has solved the research problem, then its domestic competitors will receive this information immediately, while firms in the other country will only receive it with a certain time lag. We show here that even with a small time lag, a shift in the distribution of firms from foreign to domestic may have a significant positive effect on the R&D intensity of domestic firms.

The remainder of the paper is organized as

4. Powell et al. (1996) p. 116.
5. Saxenian (1994) p. 32.
6. See e. g. Jaffe (1989), Jaffe et al. (1993), and Mansfield (1994).
7. Jaffe et al. (1993) p. 577.

follows: In section 2, we set up a two-country version of Lee and Wilde's patent race model, modified to account for information transmission lags across countries. Section 3 contains the comparative statics and discussion, and section 4 concludes.

## The model

We consider an industry populated by $n$ firms in country 1 and $m$ firms in country 2, all of whom are engaged in an R&D race in search of a new technology. A firm is said to have achieved *technological success* if it has reached an understanding of how to solve the research problem. For an academic scientist, this would be the time at which she has convinced herself by proof or intuition about the validity of a new theorem.

Each firm can generate an instantaneous technological success probability of $x$ per unit of time by spending $c(x)$ on R&D[8]. For unspecified technological reasons, $c(x)$ must be constant through time. The distribution of the random time $\tau$ for a firm with R&D intensity $x$ to achieve technological success is therefore given by

$$Pr(\tau \leq t) = 1-e^{-tx}, \qquad (1)$$

and the expected waiting time to technological success is $1/x$.

If a firm in some country achieves technological success at time $t$, then the other firms in that country get to know it at time $t$ also, while firms in the other country only get this information at time $t+T>t$. The idea is that since the innovation has not yet been documented in any way, this information has to spread through word of mouth in local networks, e. g. starting with a talk in some local seminar series in the case of the academic scientist. We assume, however, that any firm that has achieved technolocical success will immediately begin to prepare such documentation in sufficient detail to apply for international patent rights, while the academic scientist would write up a discussion paper and submit it to a journal.

Let $V>0$ denote the present value of a patent for a firm that has just achieved technological success. $V$ represents the expected monopoly profit from exclusive ownership to the innovation during the time period before the patent expires or the innovation becomes obsolete, net of any costs of preparing the patent application, but excluding sunk R&D expenditures. Due to the information time lag, it may happen that two firms in different countries submit patent applications for the same innovation. In such a case the patent rights will eventually be awarded to the earliest applicant. It therefore makes sense to say that a firm has achieved *commercial success* once it becomes publicly known that it has won the patent race. By assumption, this will happen $T$ units of time after the time of its technological success.

Note that if some firm achieves technological success at time $t$, it will be rational for the other firms in the same country to abandon their projects immediately, while firms in the other country, who have not yet been informed about this event, will continue theirs for an additional $T$ units of time, unless some other firm in the other country suceeds during the time between $t$ and $t+T$ before the first success becomes publicly known.

8. Time is continuous, and we assume that $c(\cdot)$ is strictly increasing, strictly convex and twice differentiable with $c(0) = c'(0) = 0$.

Let $x_i$ and $y_i$ denote the R&D intensity of a firm $i$ in countries 1 and 2, respectively, and let $X := \Sigma_{i=1}^{n} x_i$ and $Y := \Sigma_{i=1}^{m} y_i$ be the aggregate R&D intensities of country 1 and 2. Also let $r>0$ be a common rate of discount for the two countries.

We shall argue that the expected present value of participating in the patent race for firm $i$ in country 1 is given by the following expression:

$$\int_0^{\infty} e^{-Xt-Y(t-T)} \cdot e^{-rt} (Vx_i e^{-YT} - c(x_i))\, dt. \quad (2)$$

To see why, we consider each term in turn, beginning with $e^{-Xt-Y(t-T)}$. This is the probability at time $t$ that firm $i$ has not yet received any information that would cause it to terminate its R&D project. Clearly, the project will be terminated as soon as $i$ gets to know that some firm (possibly itself) has achieved a technological success. If firm $i$ or some other domestic firm has already succeeded, then $i$ would know it via access to its efficient domestic information network, and the first subterm, $e^{-Xt}$, is the probability at that no domestic firm has yet succeeded at time $t$. Now if some foreign firm has succeeded before time $t-T$, then $i$ would know that too, while if it succeeded during the recent $t-T$ units of time, there is no way that firm $i$ could possibly know it, due to the somewhat lesser efficiency of its international information network, and the second subterm $e^{-Y(t-T)}$ is the probability that no foreign firm succeeded before time $t-T$. The term $e^{-Xt-Y(t-T)}$ is therefore the probability at time $t$ that it is still worthwhile for firm $i$ to continue its R&D project in the hope of winning the patent race.

The term $e^{-rt}(Vx_i e^{-YT} - c(x_i))\, dt$ is the expected present value of continuing the R&D project for an additional $dt$ units of time, given that it is still worthwhile to continue. $e^{-rt}$ is the discount factor, $V$ is the value of a commercial success, and $c(x_i)$ is the R&D expenditure needed to generate the technological success probability $x_i$. The probability of a commercial success is only $x_i e^{-YT}$, however, because there is a small probability $1-e^{-YT}$ that some foreign firm succeeded so recently that $i$ has not yet been informed about it.

The expected present value of participating in the patent race for a firm in country 2 is identical to (2), except for interchanging $x_i$ and $n$ with $y_i$ and $m$, respectively. In order to solve the model, we first find the first-order conditions for optimal $x_i$ and $y_i$, and look for a symmetric Nash equilibrium where $x_i = x$ for all firms $i$ in country 1 and $y_i = y$ for all firms $i$ in country 2. Then $X=nx$, and $Y=my$, and the equilibrium R&D intensities $x$ and $y$ are defined by the following pair of equations:[9]

$$\frac{V - c'(x)e^{Tmy}}{Vx - c(x)e^{Tmy}} (r+nx+my) = 1 \quad (3)$$

$$\frac{V - c'(y)e^{Tnx}}{Vy - c(y)e^{Tnx}} (r+nx+my) = 1 \quad (4)$$

9. Evaluating the integral in (2) yields

$$\frac{Vx_i - c(x_i)e^{TY}}{r+X+Y},$$

and the first-order condition for an optimum with respect to $x_i$ is given by

$$\frac{V - c'(x_i)e^{TY}}{Vx_i - c(x_i)e^{TY}} (r+X+Y) = 1.$$

## Analysis

As a starting point for the analysis, we first consider Lee and Wilde's (1980) one-country version of the model by setting $m$, $y$ and $T$ to zero. The set of equilibrium conditions for the economy then reduces to the following equilibrium condition for the home country:

$$\frac{V - c'(x)}{Vx - c(x)}(r+nx) = 1 \qquad (5)$$

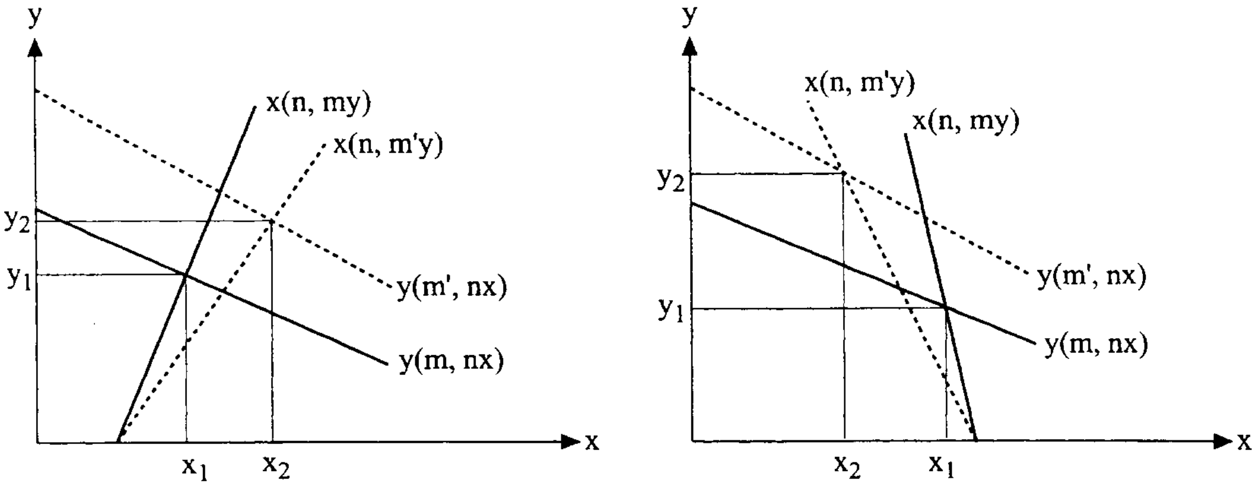
A main result of Lee and Wilde which we shall use below, is that an increase in the number of firms $n$ in the industry will increase the R&D intensity of each firm. To see this, we first observe that $1/(nx)$ is the expected waiting time to technological success for the industry as a whole. Increasing the competitive pressure $nx$ therefore reduces the expected time to technological success, which in turn reduces the expected value for any given firm of obtaining technological success in the distant future. Thus, an increase in $nx$ has the same incentive effect as an increase in the discount rate $r$, which is to increase the R&D intensity $x$ in order to realize the uncertain payoff at an earlier date. For a given R&D intensity $x$, an increase in $n$ will have the same qualitative effect, and cause $x$ to increase as well.

Turning next to the two-country version of the model, it is easy to see from equilibrium conditions (3) and (4) how information transmission lags will work on the model: To first order, an increase in $n$, the number of competitors of country 1, has two effects on the system: First, there is the positive *competition effect*, familiar from the Lee-Wilde model, which works on (3) and (4) by increasing $r+nx+my$, and calls for increases in $x$ and $y$ to restore equality in (3) and (4). Second, there is a negative *cost effect*, due to the local network information externalities, which works through the term $e^{Tnx}$ in (4) to offset the positive competition effect for firms in country 2: As the number of firms in country 1 increases, it becomes more likely that some firm in that country will be the first one to achieve technological success. This increases the cost of generating any given probability of commercial success for firms in country 2, and reduces their marginal revenue of R&D.

In order to establish the conditions under which either effect dominates, we first introduce the *aggregate reaction curves* $x(n,my)$ and $y(m,nx)$ for the home and foreign country respectively, as the solutions to (3) and (4) of $x$ in terms of $y$ and vice versa, for given values of $n$ and $m$.

Note that the foreign R&D intensity $y$ and the number of foreign firms $m$ occur in the equilibrium condition (3) for the home country only through the term $my$. This is a key structural property of the model which implies that an increase in $m$ causes a positive shift in the aggregate reaction curve $x(n,my)$ if and only if the aggregate reaction curve is positively sloped at the equilibrium. By symmetry of the model, the same argument applies to the aggregate reaction curve of the foreign country.

Obviously, what determines the slopes of the reaction curves is the size of the competition effect relative to the cost effect. An increase in the size of the information asymmetry $T$, increases the cost effect without altering the competition effect, while an increase in the number of foreign competitiors $m$ increases both effects. Note however, that the cost effect is an increasing convex function of $m$, while the competition effect varies linearly with $m$. Therefore, the positive competition effect will tend to dominate in domestic industries which do have access to close information networks with few foreign competitors, while the negative cost effect is likely to dominate in



a) Increased foreign R&D competition increases domestic R&D

b) Increased foreign R&D competition reduces domestic R&D

Figure 1: Effects of foreign R&D competition on domestic R&D intensity

domestic industries which face many foreign competitors whose R&D achievements are difficult to monitor.

This structural property may be used to establish the main result of this paper, namely that an increase in the amount of foreign R&D competition will increase the equilibrium amount of domestic R&D if and only if the aggregate reaction curve of the home country is positively sloped at the equilibrium.

The argument is illustrated in figure 1. As the number of foreign firms is increased from $m$ to $m'$, the expected waiting time to technological success is reduced, and so is the value of a technological success in the distant future. Firms therefore find it in their interest to increase their R&D efforts in order to increase their own success probabilities, and this results in an upward shift in the aggregate reaction curve of country 2. For country 2, this positive competition effect is the only one, while for country 1, there is an offsetting negative cost effect. Panel (a) illustrates a case where the information time lag $T$ is small enough for the positive competition effect to dominate the negative cost effect for domestic firms. Therefore, the net effect of increased foreign competition is positive, and the aggregate reaction curve of the home country $x(n, my)$ is upward sloping. It starts at a positive value for $y$=0, which corresponds to the equilibrium value of $x$ in the one-country version of the model. When the number of foreign competitors is increased from $m$ to $m'$, it becomes more likely that some foreign firm will win the patent race. Domestic firms will therefore be more likely to find that they have spent some R&D effort on reinventing the wheel, due to the information time lag between firms in different countries. This reduces the probability that a technological success in the home country will also be a commercial success, and hence increases the cost of generating any given commercial success probability. Ceteris paribus, this negative cost effect would cause domestic firms to do less R&D, and the aggregate reaction curve for the home country to shift leftwards. However, since the reaction curve is positively sloped at the outset, it follows by the key structural property of the model that the positive competition effect from increased $m$ will dominate the negative cost effect and cause a net shift to the right. In the figure, the end result is an increase in the equilibrium value of $x$ from $x_1$ to $x_2$, and it is obvious from the figure that this positive equilibrium effect does not depend on the slope of the reaction curve of the foreign country.

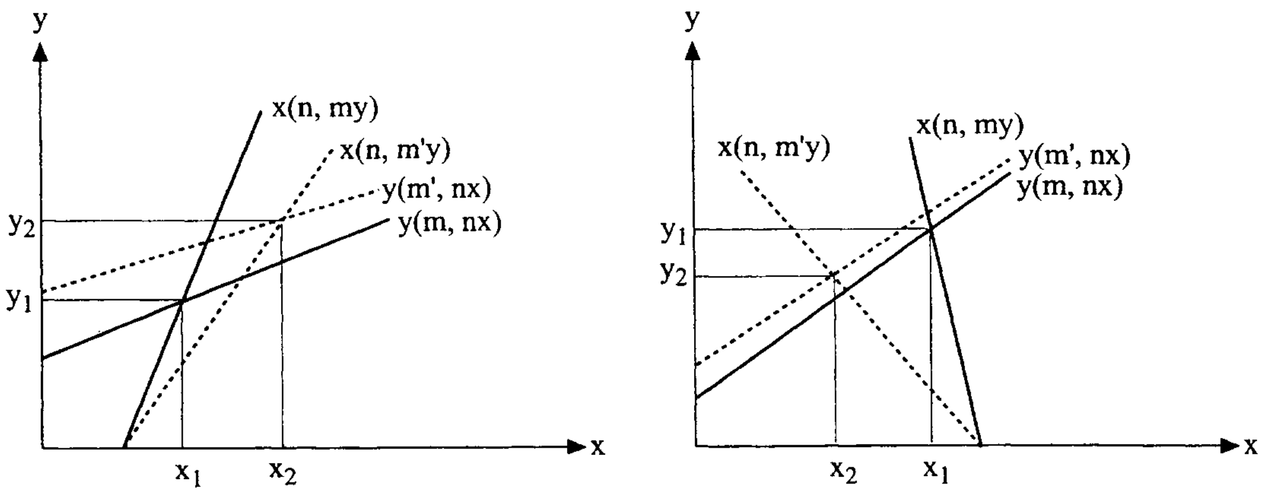
In panel (b), on the other hand, the information transmission lag $T$ is so large that the negative cost effect dominates the positive competition effect. Thus the aggregate reaction curve in the home country is downward sloping to begin with, and therefore by the key structural property of the model, an increase in the number of foreign competitors from $m$ to $m'$ results in a leftward shift in the home country's reaction curve. The end result is therefore a reduction in the equilibrium value of $x$ from $x_1$ to $x_2$, and again it is clear from the figure that this negative effect does not depend on the slope of the reaction curve of the foreign country.

It follows from this analysis that a government which would like to stimulate the R&D activity of domestic firms cannot in general rely on international R&D competition to do the job. This raises the question of whether it is always possible to increase the R&D intensity of domestic firms by stimulating startups of additional firms at home.

If we look back at figure 1, this seems to be the case, since in both cases, the equilibrium R&D intensity in country 2 increases as the result of an increase in the number $m$ of firms in country 2. However, it is also clear that it is in principle possible to get the opposite conclusion in case (a), if the positive shift in the aggregate reaction curve of country 2 is small. In case (b), however, the equilibrium R&D intensity in country 2 must necessarily increase, because the negative cost effect dominates the positive competition effect in both countries: Increasing the number of firms in country 2 then reduces the R&D intensity of firms in country 1. This yields a positive feedback on the expected profitability of R&D in country 2 which reinforces the direct positive competition effect on its R&D intensity[10]. It turns out that in general, an increase in the number of domestic competitors is guaranteed to increase the equilibrium R&D intensity at home if both reaction curves are either increasing or decreasing, while if one is increasing and the other decreasing, it is possible to get the opposite result. This is illustrated in figure 2, where in panel (a), the equilibrium effect of an increase in $m$ is positive for both countries since both reaction curves are increasing, while in panel (b) an increase in $m$ reduces the R&D intensity in country 2.

The case depicted in panel (b) of figure 2 does not arise, however, for certain plausible specifications of the cost function $c$. In particular, if $c$ is a power function, then an increase in the number of domestic competitors will always increase the R&D intensity of domestic firms. Moreover, one can then show[11] that the equilibrium satisfies many intuitively reasonable properties, such as: (i) The R&D intensity is higher in that country which has the greater number of firms, (ii) the R&D intensity of any country, relative to that of the other, is an increasing function of its share of the industry, and (iii) firms in countries with many domestic

10. We do not consider the case where both reaction curves are downward sloping and cross each other from above, since in this case, the equilibrium is unstable.
11. Proofs available from the author.




a) Increased R&D competition in country 2 increases the R&D intensity of country 2

b) Increased R&D competition in country 2 reduces the R&D intensity of country 2

Figure 2: Effects of R&D competition in country 2 on R&D intensity in country 2

competitors are more profitable than firms in countries with fewer domestic competitors.

Result (ii) implies that a country which increases its share of an R&D intensive industry, e.g. through new startups, will experience an increase in its share of the innovations made in that industry, first because its share of the total number of innovating firms increases, and second, because all firms located in the home country will innovate more, relative to foreign firms, than before. To the extent that growth is driven by innovations, this means that ceteris paribus, countries will tend to grow at the fastest pace in those industries in which they have a large share at the outset. Result (iii) suggests that this tendency will be even stronger in a world of mobile capital: Since firms in countries with many domestic competitors are more profitable than firms in countries with fewer domestic competitors, there will be a tendency for firms to move their activities to the country which has the largest share of the industry at the outset.

We close this section with some numerical examples to illustrate the properies of the model with power cost functions of the form $c(x) = x^{\alpha}$. The results are illustrated in Table 1, for various values of $T$, $\alpha$ and $n$, and where $m = 2$, $r$=0.1 and $V$=1 in all cases.

| | | | | Country 1 | | Country 2 | |
|---|---|---|---|---|---|---|---|
| T | α | n | m | R&D int. | Profits | R&D int. | Profits |
| 0.1 | 1.5 | 2 | 2 | 0.322 | 0.091 | 0.322 | 0.091 |
| 0.1 | 1.5 | 10 | 2 | 0.385 | 0.031 | 0.199 | 0.016 |
| 0.1 | 1.05 | 2 | 2 | 0.156 | 0.013 | 0.156 | 0.013 |
| 0.1 | 1.05 | 3 | 2 | 0.190 | 0.013 | 0.106 | 0.006 |
| 0.2 | 1.5 | 2 | 2 | 0.291 | 0.091 | 0.291 | 0.091 |
| 0.2 | 1.5 | 10 | 2 | 0.386 | 0.033 | 0.094 | 0.008 |
| 0.2 | 1.05 | 2 | 2 | 0.116 | 0.012 | 0.116 | 0.012 |
| 0.2 | 1.05 | 3 | 2 | 0.213 | 0.017 | 0.028 | 0.002 |

Table 1: Numerical examples with $r$=0.1 and $V$=1.

The first two rows describe an experiment where $\alpha = 1.5$ and where initially, $n = m = 2$, which yields a symmetric equilibrium with an R&D intensity of 0.322 and expected profits equal to 0.091 for firms in both countries. We then consider an increase in $n$ from 2 to 10. This is seen to yield a new equilibrium where the R&D intensities for firms in country 2, as well as their expected profits, are reduced to some 50 per cent of the corresponding values for country 1.

In rows 3 and 4, we consider a less convex cost function with $\alpha = 1.05$, and obtain effects of a similar order of magnitude by increasing the number of firms in country 1 from 2 to 3 only. Thus, we see that the negative externalities from information lags are greater, the smaller are the diseconomies to scale in R&D. Note that in the initial situation of row 3, the expected waiting time to technological success is $1/(4 \cdot 0.156) \approx 1.6$, as compared to an information transmission lag of 0.1 units of time. This illustrates that even with a small information transmission lag relative to the expected time to technological success, an increase in the number of foreign competitors may have a substantial negative effect on domestic R&D intensity. In rows 5 through 8 of the table, the two experiments just described have been repeated for $T$=0.2, which is seen to yield effects which are approximately twice as large as the effects for $T$=0.1.

## Conclusion

The literature on endogeneous growth has pointed out that international asymmetries in accumulated knowledge may grow larger over time to create international specialization and local agglomeration in knowledge based industries. The mechanism that drives such results is that knowledge spillovers occur faster locally than globally, which creates positive external effects among domestic firms and comparative advantages for a country in those industries where the aggregate level of accumulated knowledge is relatively high compared to that of other countries. In this paper, we have identified another mechanism that might generate the same type of specialization and agglomeration effects, even if knowledge is a perfectly excludable good which generates no spillovers. In our model, knowledge that some other firm has aquired some valuable piece of knowledge is valuable as well, because it enables firms to manage their R&D activities more efficiently. This limited form of knowledge spillovers is shown to create a similar local externality, as long as this information too spreads faster within nations than between them. We give an explicit representation of the local information networks which form the basis of this asymmetry, and show that the profitability of firms in an industry which is large compared to its foreign counterpart will be higher than the profitability of foreign firms in the same industry. Hence in an economy with many industries and international capital markets, there will be a tendency for a country to grow in those industries in which it has a large industrial base at the outset. This indicates that local agglomeration in R&D intensive industries may result even if knowledge spillovers are non-existent or global, as long as information transmission in the very short run is slightly imperfect, due to information networks that are stronger locally than globally. An interesting topic for further investigation would be to embed the model presented here in a general equilibrium framework in order to explore this idea in more detail.

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