Basic R&D in vertical markets*

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December, 2006

Abstract

This paper deals with the role of basic R&D investment in vertical markets where an incumbent owner of a basic technological input faces potential competition. We show that the socially optimal investment in basic research is the maximum level of this variable such that this basic R&D effort, in fact, is never applied.

Keywords: innovation, basic research, technology transfer, entry deterrence.

JEL Classification: L12, L42, L53, O38.

*We thank Ramón Caminal, Luis Corchón, M.Paz Coscollá, Chrysovalantou Milliou and seminar audiencies at the EARIE 2006 Conference in Amsterdam and at the XXII Jornadas de Economía Industrial in Barcelona for their very useful comments. We acknowledge financial support from the Spanish Ministry of Science and Technology under projects BEC2003-01132 and SEJ2005-07200/ECON (M. González Maestre), BBVA under project 02255 (M. González-Maestre) and the Vicerectorat d'Investigació de la Universitat de València under project UV-AE-20041030 (L.M. Granero). The usual disclaimer applies.

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1 Introduction

This paper is concerned with the role played by basic R&D investment in vertical markets where a basic technological input is needed in the production of a final good. Examples include the pharmaceutical, electronics or computer industries, where previous knowledge, obtained by means of basic R&D effort, is needed before its application to the production of final goods. In a variety of cases, a large part of this basic research is undertaken by public research centers, including universities or scientific institutes, in a context where most of the empirical evidence points to a positive relationship between public and private R&D expenditures.[1]

There are several arguments justifying the public intervention to stimulate basic R&D investment, particularly when a long-run causality emerges from public R&D expenditure to private R&D expenditure (e.g., see Yoo, 2004). Most people, in fact, do believe that public R&D can contribute to economic performance through its impact on industrial productivity growth. However, the empirical evidence points out that privately funded R&D in manufacturing industries yields a relevant premium over the rates of return from public R&D (e.g., Griliches, 1995). According to this evidence, one could conclude that public R&D should not to be expected to have a relevant direct impact on industrial productivity. Beyond that, public funding of R&D can also enhance economic performance indirectly by complementing and stimulating private R&D expenditures, even if it has been undertaken with other purposes in view (David et al, 2000). In this case, public R&D is sometimes assigned to public institutes and national laboratories characterized by generating basic R&D that may encourage applied R&D investments by firms on the grounds of knowledge spillovers.[2] Our work contributes to this literature by focusing on the role played by public investment in basic R&D on the degree of competition in vertically related markets. In particular, we show that a government maximizing overall welfare might be interested

[1] Among others, see Lichtenberg (1987), Ward and Dranove (1995), and Guellec and van Pottelsberghe (2003). For a survey, see David et al. (2000).

[2] For instance, Ward and Dranove (1995) examine the relationship between basic and applied pharmaceutical research by focusing on government-funded basic research, publication in medical journals, and industry-funded applied R&D. These authors estimate that a one percent increase in basic research in a particular therapeutic category leads to a 0.76 percent increase in industry R&D in that category, and a 1.71 percent increase in other categories, over seven years.

in financing basic R&D activities even if these activities are not applied in equilibrium. The intuition behind this apparently paradoxical result can be explained as follows. In many markets, producers of a final good (computers, pharmaceuticals, etc.) usually depend on some basic technological input patented by an upstream supplier (operating systems, the formulae to obtain a pharmaceutical product, etc.). Under these conditions, public intervention might contribute to the development of substitutive technological inputs in order to stimulate a more competitive behaviour of incumbent owners of this type of inputs. However, since the basic R&D is usually accompanied by substantial applied investment, the associated increasing returns to scale imply that, under reasonable conditions, the optimal policy should deter the useless replication of this applied R&D. Thus, on the one hand basic R&D is needed in order to "discipline" the incumbent upstream firm, but on the other hand replication of applied R&D should be avoided. Of course, there is also an inefficiency associated with the development of the basic research which is not finally applied, but it turns out that this research is necessary to make it credible the threat of applying alternative knowledge inputs under too expensive prices of existing technological inputs.[3]

Our analysis suggests that government-funded basic research can have an indirect impact on economic performance through its influence on the strategic behaviour of firms in vertical markets with upstream technological inputs. Based on that, our work is related to some recent contributions in the context of those markets. In particular, Hall and Hall (2000) have calibrated an oligopoly model to quantify Microsoft's conduct, showing that their results are consistent with the idea that Microsoft sets the price of Windows to deter self-supplying of alternative operating systems by computer manufacturers. A similar analysis is undertaken in Hall (2000), while Fudenberg and Tirole (2000) have emphasized the role of network externalities to illustrate the effects of entry-deterrence pricing in those technological markets (see also the evidence by Foncel and Ivaldi, 2005). Neither of these works, however, has focused on the role of public investment on R&D as a device to reach optimal levels of welfare.

The rest of the paper is organized as follows: Section 2 presents the model, Section 3 deals with the welfare analysis, and Section 4 concludes.

[3] An example of this type of behaviour corresponds to the development of the so-called "free software" or "freeware" by universities and governments in a number of countries, including the development of several variants of Linux (e.g., Linex).

2 The model

Let us consider two vertically integrated markets where the upstream market provides a basic technological input (e.g., operating system) to a downstream industry (e.g., computer manufacturers). As in Hall (2000), in the upstream market there is a single supplier of the technological input to M downstream firms selling the final consumption good. Additionally, there are N potential self-supplying firms in the downstream market. In order to become active, each of these potential firms must develop an alternative technological input which involves a total fixed cost $A > 0$ in the absence of government intervention. The demand of the final homogeneous good is given by $p = a - x$, where x is total output and p is the price.

The role of the government is determined by the possibility of public investment in R&D. We denote by α the proportion of A subsidized by the government (where $0 \leq \alpha \leq 1$). We will interpret αA as the basic R&D devoted to develop a new technology (e.g., a new operating system). Since this basic research is a non-rival good, once it has been developed, the government can allow more than one firm to use this technological input at zero cost. Then, in order to be able to produce, each firm must pay a fixed cost $(1-\alpha)A$, which can be interpreted as the complementary applied R&D effort necessary to implement the basic knowledge obtained by the government. In contrast to the basic research, applied R&D is assumed to be a rival good. This assumption is reasonable if we think about $(1 - \alpha)A$ as the specific effort that each firm has to undertake in order to learn and apply the new technology. Our formulation implies that this extra effort is lower the greater the volume of basic R&D (for instance, by increasing α the government can decrease to a relevant extent the difficulties associated with the application of the new technology).

The basic R&D effort undertaken by public entities can be interpreted in different ways. In the context of the computer and internet industries, a relevant aspect of this basic research has to do with the compatibility between new alternative hardware or software and previously existing technological inputs. In line with this interpretation, the so-called "free software" currently developed by a variety public institutions, including universities, faces the important problem of developing compatibilities with prevalent devices and operating systems. Other relevant aspect regarding the potential applicability of basic R&D is the dissemination of knowledge, where technology transfer offices may play a crucial role (e.g., see Macho-Stadler, Pérez-Castrillo and

Veuglers, 2005).

We deal with a three-stage game as in Hall (2000). At the first stage, the upstream monopolist sets the same two-part tariff (r, L) for each of its M downstream customers, where L is a lump-sum component and r is a unit tariff. At the second stage, each potential entrant decides whether to enter or not the market (which involves the payment of a fixed cost $(1-\alpha)A$). Finally, at the third stage, Cournot competition takes place among the active firms in the final good market. The cost functions of each customer of the upstream firm and each self-supplying firm are given, respectively, by $C_c(x_c) = (c + r)x_c + L$ and $C_s(x_s) = cx_s + (1-\alpha)A$, where $0 \leq c < a$, and x_c and x_s denote each of these firms' output levels, accordingly.

As is shown by Hall (2000), for a sufficiently large number of potential entrants, the upstream firm's optimal strategy is to set r such that entry of self-supplying firms is deterred.[4] However, if the number of potential entrants is not too large, the incumbent supplier must choose between deterring or accommodating entry. In the following analysis we consider both possibilities.

Once the supplier has chosen r, the asymmetric Cournot equilibrium with M customer and $n \leq N$ self-suppliers gives the following individual and total output and price

$$x_c = \frac{a - c - (n+1)r}{M + n + 1}, \quad x_s = \frac{a - c + Mr}{M + n + 1}, \tag{1}$$

$$x = \frac{(M + n)(a - c) - Mr}{M + n + 1}, \tag{2}$$

$$p = \frac{a + Mr + (M + n)c}{M + n + 1}. \tag{3}$$

The profit of a self-supplying active firm is given by

$$\pi_s = \left(\frac{a - c + Mr}{M + n + 1}\right)^2 - (1 - \alpha)A. \tag{4}$$

[4] Variants of this result have been previously obtained by Gilbert (1986), Corchón and Marcos (1988), and Vives (1988) in the context of the so-called "limit price" models.

Since the upstream firm uses the lump-sum part of the contract to absorb all the profits of the M customer firms, the profit earned by the upstream supplier with M customers and n self-suppliers will be given by

$$\pi_u = M \left(\frac{1}{M+n+1} \right)^2 (a-c+Mr)(a-c-(n+1)r)\,. \tag{5}$$

Under accommodation, the profit-maximizing level of r, given n and M, is

$$r_A(n,M) = \frac{(M-n-1)(a-c)}{2M(n+1)}, \tag{6}$$

which inserted into (5) gives upstream firm's profit under accommodation with n active self-supplying firms:

$$\pi_A(n,M) = \frac{(a-c)^2}{4(n+1)}. \tag{7}$$

From expression (4) it follows that the value of r that would yield zero profits with n self-supplying downstream firms is

$$r = \frac{\delta(M+n+1)-(a-c)}{M}, \tag{8}$$

where $\delta = \sqrt{(1-\alpha)A}$. Since the n-th self-supplying firm does not actually enter the market at this price, it turns out that the value of r that results in the entry of n firms is

$$r_D(n,M) = \frac{\delta(M+n+2)-(a-c)}{M}. \tag{9}$$

Inserting this expression into (5) yields the upstream firm's profit as a function of n in the case of (partial) entry deterrence with n self-supplying active firms:

$$\pi_D(n,M) = \delta\frac{M+n+2}{M+n+1}\left(a-c-(n+1)\frac{M+n+2}{M+n+1}\delta\right). \tag{10}$$

As was noticed by Hall (2000), this expression is strictly decreasing in n if $r_D < r_A$ (which holds for δ small enough). Therefore, if the optimal upstream firm's strategy is to deter entry then it must be the case that $n = 0$. In consequence, the upstream monopolist must compare profits under the following alternative strategies:

i) Deterring entry by setting

$$r^D = r_D(0,M) = \frac{\delta(M+2)-(a-c)}{M}. \tag{11}$$

ii) Accommodating entry with

$$r^A = r_A(N,M) = \frac{(M-N-1)(a-c)}{2M(N+1)}. \tag{12}$$

By using (7) and (10) evaluated, respectively, at $n = N$ and $n = 0$ we obtain

$$\pi^A = \pi_A(N,1) = \frac{(a-c)^2}{4(N+1)}, \tag{13}$$

$$\pi^D = \pi_D(0,1) = \frac{M+2}{M+1}\delta\left(a-c-\frac{M+2}{M+1}\delta\right), \tag{14}$$

where π^A and π^D stand for upstream profits under accommodation and entry deterrence, respectively. Normalizing such that $(a-c) = 1$, it turns out that

$$\pi^A - \pi^D = 0 \iff \frac{1}{4(N+1)} = \frac{M+2}{M+1}\delta\left(1-\frac{M+2}{M+1}\delta\right),$$

and denoting by δ' the critical value for δ in this equation such that the optimal upstream firm's strategy is entry deterrence, we can write

$$\delta'(M,N) = \frac{M+1}{M+2}\left(\frac{1}{2} - \frac{1}{2}\sqrt{\frac{N}{N+1}}\right). \tag{15}$$

In terms of α this critical value is given by

$$\alpha'(M,N,A) = 1 - \left(\frac{M+1}{M+2}\right)^2 \frac{1}{4A}\left(1 - \sqrt{\frac{N}{N+1}}\right)^2. \tag{16}$$

From our previous analysis and expression (16) we obtain or first result:

Proposition 1 *Entry deterrence is profitable for the upstream firm if and only if α is smaller than α'; otherwise, the upstream firm is interested in accommodating entry. This critical level α' is strictly increasing in A, strictly decreasing in the number of customers (M) and strictly increasing in the number of potential competitors (N).*

Intuitively, if α is greater than α' entry deterrence is too costly for the upstream firm, since it involves a too low input price. Note that α' is increasing in N because the greater the number of competitors the lower must be the input price under accomodation and the more likely is that the upstrem firm prefers to deter entry. Contrarily, α' decreases with M because with a greater number of customers the profitability of entry-deterrence is lower, while under accomodation the input price is adjusted so that the degree of competition is indendent of M (see expressions (13) and (14)).

In the next section, we investigate the socially optimal value for α, taking into account the strategic behaviour of firms.

3 Welfare analysis

In this section we consider the previous model from the social welfare point of view. Specifically, we are to obtain total welfare as a function of α in order to investigate the socially optimal level of basic R&D.

Let us define total welfare as $W = CS + \Pi - \alpha A$, where CS is consumers' surplus and Π are total profits, defined, respectively as

$$CS(x) = \int_0^x (p(t) - p(x))dt = \frac{1}{2}x^2, \tag{17}$$

$$\Pi(x, n) = \pi_u + n\pi_s = (p(x) - c)x - n(1-\alpha)A = (1-x)x - n(1-\alpha)A. \tag{18}$$

Therefore,

$$W(x, n) = x - \frac{1}{2}x^2 - n(1-\alpha)A - \alpha A. \tag{19}$$

Making use of (2), (11) and (12), we can obtain total production and welfare under accommodation and entry deterrence, respectively:

$$x^A(N) = \frac{1}{2}\left(\frac{2N+1}{N+1}\right), \tag{20}$$

$$W^A(N, A, \alpha) = \frac{(2N+1)(2N+3)}{8(N+1)^2} - NA + (N-1)A\alpha, \tag{21}$$

$$x^D(M, A) = 1 - \frac{M+2}{M+1}\sqrt{(1-\alpha)A}, \tag{22}$$

$$W^D(M, A, \alpha) = \frac{1}{2} - \frac{1}{2}\left(\frac{M+2}{M+1}\right)^2 A + \left[\frac{1}{2}\left(\frac{M+2}{M+1}\right)^2 - 1\right] A\alpha. \tag{23}$$

Since the previous expression is strictly increasing in M, it follows that

$$\begin{aligned} & W^D(M, A, \alpha) - W^A(N, A, \alpha) \\ \geq\ & W^D(1, A, \alpha) - W^A(N, A, \alpha) \\ =\ & \frac{1}{2} - \frac{(2N+1)(2N+3)}{8(N+1)^2} + (N - \frac{9}{8})A(1-\alpha) > 0, \end{aligned} \tag{24}$$

where the sign follows from noticing that $F(N) = (2N+1)(2N+3)/(8(N+1)^2)$ is strictly increasing in N, $F(N)$ tends to $1/2$ as N goes to infinity, and $W^D(1, A, \alpha) - W^A(1, A, \alpha) = (1/32) - A(1-\alpha)/8 > 0$, which is ensured by the condition of positive profits under monopoly, $A < 1/4$.

This analysis gives rise to our second result:

Proposition 2 *For any given level of α, the optimal antitrust policy is to allow for entry-deterrence pricing by the incumbent supplier.*

This result conforms to the conjecture formulated by Hall and Hall (2000) that entry-deterrence pricing used by Microsoft in order to deter the development of alternative operating systems might be, actually, welfare-enhancing. The basic argument is that the full development of alternative operating systems involves a socially wasteful replication of R&D efforts. However, those authors also note that, in order to lower this entry-deterrence price, antitrust regulation must control for other aspects of Microsoft's conduct, like contracts, technological compatibilities, etc. In the following analysis we propose an alternative, possibly more efficient pro-competitive policy: using the level of public investment in R&D (represented by α) as a way of reducing the price of the incumbent's technological good.

According to our previous result, for any α social welfare is greater under entry deterrence. However, this is only the optimal incumbent's strategy if α is lower than the critical level α' defined in (16). Otherwise, total welfare is determined by the accommodating strategy of the incumbent firm. Therefore, total welfare is a function of α given by

$$W(N, A, \alpha) = \begin{cases} W^D(M, A, \alpha) & \text{if } \alpha \leq \alpha' \\ \\ W^A(N, A, \alpha) & \text{if } \alpha > \alpha' \end{cases} \tag{25}$$

with $W^D(M, A, \alpha)$ and $W^A(N, A, \alpha)$ as in (21) and (23) above. The function $W(M, N, A, \alpha)$ is represented in Figure 1 at the space (α, W) for any $N \geq 1$.

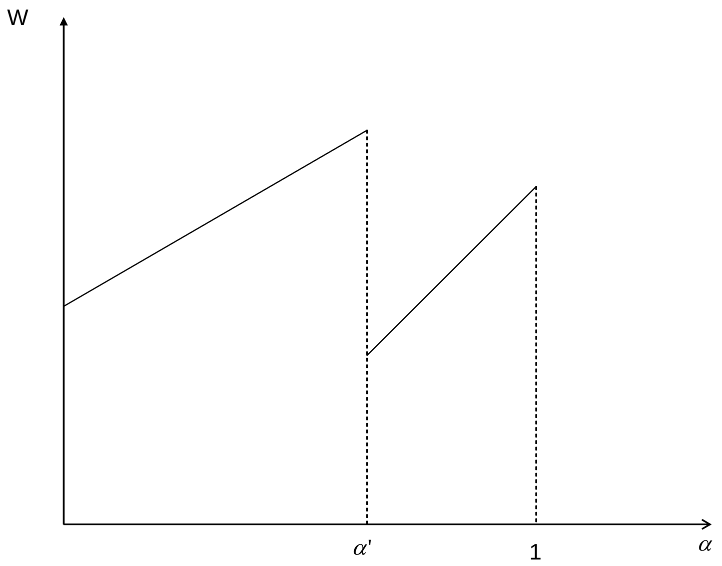

Figure 1: Welfare as a function of α.

Making use of expression (16), we can show that

$$\begin{aligned}
& W^D(M, A, \alpha'(M, N, A)) - W^A(N, A, 1) \\
= \; & \frac{1}{2} - \frac{(2N+1)(2N+3)}{8(N+1)^2} \\
& - \left[\frac{1}{2} \left(\frac{M+2}{M+1} \right)^2 - 1 \right] (1 - \alpha'(M, N, A))A \\
= \; & \frac{1}{2} - \frac{(2N+1)(2N+3)}{8(N+1)^2} \\
& - \frac{1}{8} \left(1 - 2 \left(\frac{M+1}{M+2} \right)^2 \right) \left(1 - \sqrt{\frac{N}{N+1}} \right)^2 \qquad (26)
\end{aligned}$$

Given that the previous expression is strictly increasing in M we have

$$
\begin{aligned}
& W^D(M, A, \alpha'(M, N, A)) - W^A(N, A, 1) \\
\geq\ & W^D(1, A, \alpha'(1, N, A)) - W^A(N, A, 1) \\
=\ & \frac{1}{2} - \frac{(2N+1)(2N+3)}{8(N+1)^2} - \frac{1}{72}\left(1 - \sqrt{\frac{N}{N+1}}\right)^2. \qquad (27)
\end{aligned}
$$

From this expression, $\partial[W^D(1, A, \alpha'(1, N, A)) - W^A(N, A, 1)]/\partial N < 0$ for all $N \geq 1$, and $\lim_{N\to\infty}[W^D(1, A, \alpha'(N, A)) - W^A(N, A, 1)] = 0$. As a consequence, $W^D(M, A, \alpha'(M, N, A)) > W^A(N, A, 1)$ for any $N \geq 1$.

We can thus summarize our results in this section in the following:

Proposition 3 *The socially optimal value of α is given by $\alpha^* = \alpha'$, which is the maximum value of α that induces the incumbent supplier of the technological good to set a price that deters the application of the new alternative technology.*

The economic explanation of this proposition can be illustrated by means of Figure 1 which depicts the function $W(M, N, A, \alpha)$. The interesting aspect in this result is that the government helps in undertaking the basic R&D investment necessary to develop a technology, but this investment is never applied in equilibrium. Intuitively, the government uses α as a disciplinary tool to control the incumbent's behaviour. The key aspect of this discipline device is that by undertaking more basic research, the government makes the threat of self-supplying credible in the case where relatively high prices are charged by the incumbent for its technology. Put in other terms, in this case, increasing α till the critical value α' allows the government to reach simultaneously two objectives: inducing a lower input price by increasing α and avoiding duplication of applied R&D investment.

4 Conclusions and final comments

Our main insight is that there is a role for public investment in R&D that seems to have been overlooked in the literature. In particular, we show that the optimal level of basic R&D in our model is such that the alternative technology is never developed in equilibrium. The explanation of this result is that basic research plays a crucial role in inducing a more competitive behaviour on behalf of the incumbent supplier of knowledge goods. This role is based on the idea that basic R&D makes the potential development of alternative technologies credible by reducing their application costs.

One interesting implication of our model is that a Research Joint Venture (RJV) might be socially undesirable. To see this, note that our parameter α can be also interpreted as the basic research investment paid by (potential) self-suppliers of the technological good. Our model suggests that if the development of this basic R&D is followed by the actual application of an alternative technological input (as is usually the objective of private RJVs) then the final outcome is likely to be wasteful.[5] If the conditions of our model are satisfied, the optimal policy would be to discourage the formation of the RJV and, instead, developing a public program of basic research.

Finally, another policy implication from our results, regarding antitrust analysis, is that they may weaken the arguments against anti-predation behaviour. In fact, our model suggests that the entry-deterrence behaviour by the incumbent supplier is socially efficient, under some conditions, since it avoids useless duplication of applied investments. However, this entry-deterrence behaviour should be regulated by the government through the appropriate level of basic R&D investment.

References

[1] Corchón, L. and Marcos, F (1988) "Entry, Stackelberg equilibrium and reasonable conjectures." *International Journal of Industrial Organization*, 6(4), 509-515.

[2] David, P.A., Hall, B.H. and Toole, A.A. (2000). "Is public R&D a complement or a substitute for private R&D? A review of the econometric evidence." *Research Policy*, 29(4-5), 497-529.

[3] Foncel, J. and Ivaldi, M. (2005). "Operating system prices in the home PC market." *Journal of Industrial Economics*, 53(2), 265-297.

[4] Fudenberg, D. and Tirole, J. (2000) "Pricing a network good to deter entry." *Journal of Industrial Economics*, 48(4), 373-390.

[5] Examples of this type of RJV include the development of alternative formats for DVDs by different RJVs formed by several producers of music, video and electronics; and the RJVs formed by some Chemestry's shops to develope a new tothpaste.

[5] Gilbert, R. (1986) "Pre-emptive competition." In J. Stiglitz and G.G. Mathewson (eds.) *New developments in the Analysis of Market Structure*, MIT Press, Cambridge, MA.

[6] Griliches, Z. "R&D and productivity: econometric results and measurement issues." In P. Stoneman (ed.) *The Handbook of the Economics of Innovation and Technological Change*, Basil Blackwell, Oxford.

[7] Guellec, D. and Van Pottelsberghe, B. (2003). "The impact of public R&D expenditure on business R&D." *Economics of Innovation and New Technologies*, 12(3), 225-244.

[8] Hall, R.E. (2000) "Optimal contracts to defend upstream monopoly." Mimeo, Hoover Institution and Department of Economics, Stanford University.

[9] Hall, C.E. and Hall, R.E. (2000) "Toward a quantification of the effects of Microsoft's conduct." *American Economic Review,* 90(2), 188-191.

[10] Lichtenberg, F.R. (1987). "The effect of government funding on private industrial research and development: a re-assessment." *Journal of Industrial Economics*, 36(1), 97-104.

[11] Macho-Stadler, I., Pérez-Castrillo, D. and Veugelers, R. (2005) "Licensing of university inventions: the role of a technology transfer office." Working paper, Fundación BBVA.

[12] Vives, X. (1988) "Sequential entry, industry structure and welfare." *European Economic Review*, 32(8), 1671-1687.

[13] Ward, M.R. and Dranove, D. (1995). "The vertical chain of research and development in the pharmaceutical industry." *Economic Inquiry*, 33(1), 70-87.

[14] Yoo, S.-H. (2004). "Public R&D expenditure and private R&D expenditure: a causality analysis." *Applied Economics Letters*, 11(11), 711-714.