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STEPHEN MARTIN

European University Institute, Florence

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STEPHEN MARTIN

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Stephen Martin

European University Institute

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Abstract: R & D joint ventures induce individual firms to reduce investment in R & D, but are socially beneficial because they ensure greater competition in the post-innovation market. It is not usually optimal for all firms to combine in a single R & D joint venture. If R & D joint ventures are formed voluntarily by firms that seek to maximize their expected value, they will not, in general, adopt the socially optimal structure of R & D joint ventures.

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I. Introduction

A growing theoretical and empirical literature examines the consequences of cooperative investment in research and development for market performance.[1] I pursue this question using the model of patent races under uncertainty pioneered by Loury [1979], Dasgupta and Stiglitz [1980], and Lee and Wilde [1980].[2]

The results may be summarized as follows. In this class of model, R & D joint ventures induce individual firms to reduce investment in research and development, and therefore delay the expected time of until successful innovation. Nonetheless, R & D joint ventures are in general socially beneficial, because they ensure greater competition in the post-innovation market.

But in a market system, it is not usually optimal for all firms to combine in a single R & D joint venture. The socially optimal structure of R & D investment under a market system is determined by a tradeoff between combined R & D activity - which ensures rivalry once the new technology is in place - and independent R & D activity - which ensures competition for the right to use the new technology. Further, if R & D joint ventures are formed voluntarily by firms that seek to maximize their expected value, they will not, in general, adopt the socially optimal structure of R & D joint ventures.

Finally, I examine the welfare consequences of production joint ventures, formed to use the new technology in competition with parent

1. See d'Aspremont and Jacquemin [1988] and Henriques [1990], and for a wide-ranging discussion, Katz and Ordover [1990]. Scott [1988, 1989] discusses U.S. experience with the National Cooperative Research Act of 1984.

2. For surveys of this literature, see Baldwin and Scott [1987], Beath, Katsoulacos, and Ulph [1989], and Reinganum [1989]

firms that are able to compete using the old technology. Such production joint ventures increase the profit of parent firms, but deny consumers any of the benefits that flow from successful innovation.

II. Independent R & D[3]

A. Firm Value

N firms compete as Cournot quantity-setting oligopolists in a product market with linear inverse demand curve $p = a - bQ$, using a technology with constant marginal and average cost c_1 per unit.[4] They also compete to discover a new technology with marginal cost $c_2 < c_1$.

The parameter $h_i \geq 0$ measures the intensity of firm i's research effort. The time at which firm i's research project will be completed is a random variable, τ_i, with exponential distribution

$$\text{(1)} \qquad \text{Prob}\ [\tau_i \leq t] = 1 - e^{-h_i t} .$$

The expected time of completion of project i is therefore

$$\text{(2)} \qquad E(\tau_i) = \int_{\tau_i=0}^{\tau_i=\infty} \tau_i h_i e^{-h_i \tau_i} d\tau_i = \frac{1}{h_i} .$$

The greater the firm's research effort, the sooner the expected time of completion of the research project.

An R & D project at intensity h requires an expenditure z(h) per unit time as long as the project is underway. The properties of the

3. The discussion of the basic model, which is well known, is kept as short as possible.

4. See Delbono and Denicolo [1990] for a discussion of the price-setting case.

cost function z(h) are[5]

(3) $$z'(h) > 0 \qquad z''(h) > 0 \ .$$

Before successful innovation, each firm earns a profit

(4) $$\pi_C(c_1) = b\left(\frac{S_1}{n + 1}\right)^2$$

per unit time, where $S_1 = (a - c_1)/b$.

If each firm conducts an independent R & D project, the winner in the R & D race obtains an infinitely-lived patent on the new technology. Losers are able to continue to compete as Cournot oligopolists, using the old technology, if they find it profitable to do so. If the most profitable option for losers is to shut down, the innovation is termed drastic. Otherwise, it is non-drastic.

After discovery of the new technology, Cournot oligopoly payoffs per unit time period are

(5.1) $$\pi_W = b\left[\frac{nS_2 - (n - 1)S_1}{n + 1}\right]^2 \qquad \pi_L = b\left(\frac{2S_1 - S_2}{n + 1}\right)^2$$

per unit time if the innovation is not drastic, and

(5.2) $$\pi_W = b\left(\frac{S_2}{2}\right)^2 \qquad \pi_L = 0$$

if the innovation is drastic, where $S_2 = (a - c_2)/b$.[6]

From the time of discovery, the value of the winner of the patent race is π_W/r, the present-discounted value of its income stream after

5. It is common to assume that z(h) displays decreasing cost over an in an initial range; such an assumption would not alter the results below, as second-order conditions require that equilibrium occur where $z''(h) > 0$.

6. Cournot equilibrium output for losers is $q_L = (2S_1 - S_2)/(n + 1)$. This will be positive for $a - c_1 > c_1 - c_2$, in which case the innovation is not drastic. Otherwise, the innovation is drastic, losers shut down, and the winner is a monopolist using the new technology.

discovery. Similarly, the value of a loser, from the time of discovery, is π_L/r.

The expected present discounted value of firm i is the expected present discounted value of its income streams before and after discovery,

$$V_i = \int_{t=0}^{\infty} e^{-(r + \sum_k h_k)t} \left[\pi_C - z(h_i) + \frac{h_i \pi_W(c_1,c_2) + (\sum_{k \neq i} h_k)\pi_L}{r} \right]$$

(6)

$$= \frac{\pi_C - z(h_i) + \frac{h_i \pi_W + (\sum_{k \neq i} h_k)\pi_L}{r}}{r + \sum_k h_k}$$

On some rearrangement of terms, the first-order condition for maximization of V_i is

(7) $$\left(r + \sum_k h_k \right) \left[\frac{\pi_W}{r} - z'(h_i) \right] = \pi_C - z(h_i) + \frac{h_i \pi_W + (\sum_{k \neq i} h_k)\pi_L}{r} .$$

Because firms are symmetric, in equilibrium all firms will chose the same research intensity.[7] Letting $h_i = h_k = h$ in (7), equilibrium research intensity is given by

(8) $$(r + nh)\left[\frac{\pi_W}{r} - z'(h) \right] = \pi_C(c_1) - z(h) + \frac{\pi_W + (n - 1)\pi_L}{r}h$$

From (7) and (8), equilibrium expected value per firm when firms carry out independent research and development is

(9) $$V_{ind} = \frac{\pi_W}{r} - z'(h) .$$

B. Welfare With Independent R & D

The instantaneous probability that innovation has not occurred is $\exp[-(\sum_k h_k)t]$. Before innovation, the market is an n-firm oligopoly in

7. If it is profitable for a single firm to undertake R & D if no other firms do so, then reaction curves have slope less than one in the neighborhood of equilibrium, equilibrium h falls as n rises and rises as $c_1 - c_2$ rises.

which all firms have marginal cost c_1 per unit. Consumers' surplus is

(10) $$\frac{b}{2}\left(\frac{n}{n+1}S_1\right)^2$$

per unit time period.

The instantaneous probability that innovation has occurred is $(\sum_k h_k)\exp[-(\sum_k h_k)t]$. In the post-innovation market, consumer's surplus is

(11.1) $$\frac{b}{2}\left(\frac{S_2}{2}\right)^2$$

per unit time if innovation is drastic, and

(11.2) $$\frac{b}{2}\left(\frac{S_2 - (n-1)S_1}{n+1}\right)^2$$

otherwise.

Multiplying pre- and post-innovation consumers' surplus by the appropriate probability density and integrating over all future time, expected consumers' surplus is

(12.1) $$CS_D^i = \frac{b}{2}\,\frac{\left(\frac{nS_1}{n+1}\right)^2 + \frac{nh}{r}\left(\frac{S_2}{2}\right)^2}{r + nh},$$

if the innovation is drastic, or

(12.2) $$CS_{ND}^i = \frac{b}{2}\,\frac{\left(\frac{nS_1}{n+1}\right)^2 + \frac{nh}{r}\left[\frac{S_2 + (n-1)S_1}{n+1}\right]^2}{r + nh}$$

if not.

Expected net social welfare is expected consumers' surplus plus the expected value of the firms in the market.

III. Complete R & D Joint Ventures

I consider a legal regime that allows firms to pool R & D activities, while constraining them to make independent output decisions. Each firm in an R & D joint venture conducts an R & D project. If any R & D project of the joint venture succeeds, all firms in the joint venture have access to the new technology.

A. Theory

Levels of R & D intensity for firms in the joint venture are selected to maximize the members' expected value, given that outputs will be determined noncooperatively. Since there are decreasing returns to R & D intensity, firms in an R & D joint venture will chose a common level of R & D intensity for each R & D project. If the joint venture includes all firms in the market, the expected value of a single firm is

$$V_j = \frac{\pi_c(c_1) - z(h) + \frac{nh\pi_c(c_2)}{r}}{r + nh}, \tag{13}$$

where $\pi_c(c_i)$ is per-firm Cournot oligopoly profit if all firms operate with marginal cost c_i. Joint venture research intensity, which maximizes (13), must satisfy the first-order condition

$$(r + nh_j)\left[\frac{n\pi_c(c_2)}{r} - z'(h_j)\right] = \left[\pi_c(c_1) - z(h_j) + \frac{n\pi_c(c_2)}{r}h_j\right] \tag{14}$$

It follows that the equilibrium value of a single firm is

$$V^*_{jv} = \frac{\pi_c(c_2)}{r} - \frac{z'(h_j)}{n} \tag{15}$$

Since the joint venture allows all firms access to the new technology, the market is an n-firm Cournot oligopoly before and after innovation. Expected consumers' surplus, by an argument similar to that which yields (12), is

$$CS^{jv}_{ND} = \frac{b}{2}\left(\frac{n}{n+1}\right)^2 \frac{s_1^2 + \frac{nh_j}{r}s_2^2}{r + nh_j} \tag{16}$$

As with independent research and development, expected net social welfare is expected consumers' surplus plus the expected value of firms in the market.

Table 1: Relative market performance, rivalry vs. R & D joint venture ($p = 100 - Q$)

$c_1 = 90$, $c_2 = 10$, $z(h) = 1000h + 10{,}000h^2$, $r = 1/10$

N		h	1/nh	Value	NSW
2	Ind	0.67019	0.74	5,846.18	21,129.84
	JV	0.24392	2.05	6,060.80	27,097.35
3	Ind	0.77925	0.43	3,665.07	20,716.42
	JV	0.18525	1.80	3,494.18	29,832.57
4	Ind	0.82951	0.30	2,659.77	20,477.20
	JV	0.14857	1.68	2,247.17	31,221.32
5	Ind	0.85822	0.23	2,085.60	20,330.35
	JV	0.12360	1.61	1,555.58	32,034.26

B. Quadratic R & D Cost Function

If the R & D cost function is quadratic, the equations that define the equilibrium values h and h_j are quadratic. They are capable of explicit solution, which allows comparison of expected firm value, consumers' surplus, and net social welfare under independent and joint R & D.

Table 1 shows typical equilibrium values under independent and joint R & D for a quadratic r & d cost function.[8] Three results stand out. First, equilibrium firm investment in R & D is lower, and expected time to successful innovation is longer, under an R & D joint venture. Under an R & D joint venture, each firm has a reduced incentive to invest in R & D: its own research program, if successful, will benefit its rivals, and it may well gain access to the new technology when some other firm completes its R & D project.

8. The values reported in Tables 1, 2, 3, and 4 are produced by a set of BASIC and Borland's EUREKA programs, which are available on request.

Second, expected net social welfare is greater if R & D is joint rather than independent. Even though joint R & D delays innovation, it ensures competition in the provision of the product after innovation occurs. The increase in consumers' surplus that results from competition in the use of the new technology is more than sufficient to outweigh the delay in its introduction.

Third, there is no reason to think that firms will voluntarily adopt socially beneficial joint R & D. Competition in the post-discovery market reduces the expected per-firm payoff that follows from successful innovation. If the number of firms is small, relative to R & D cost and the size of the innovation, then post-innovation oligopoly profit is large enough so that firms' values are greater under a joint R & D program than with independent research. For the example of Table 1, a complete R & D joint venture yields firms a greater expected value than independent duopoly R & D. But if there are more than two firms, setting up an R & D joint venture reduces firms' expected value, because it reduces expected post-innovation profit. Generally, if the number of firms is large enough, it is more profitable to take a chance on having monopoly access to the new technology than to be assured of having shared access to the new technology.

IV. The Structure of R & D Cooperation

But if there are more than two firms, it may be profitable for some firms to form joint ventures, while other firms find it most profitable to carry out independent R & D programs. This raises the question of the market equilibrium and optimal structures of R & D activity.

The appropriate equilibrium concept depends on whether or not firms can exclude rivals from a partial R & D joint venture. If firms in an R & D joint venture can exclude rivals, then a partition of firms into joint ventures and a fringe of independent researchers is an equilibrium if no firm in a joint venture can increase its expected value by defecting to the fringe and no group of firms in the fringe can increase their expected values by forming a joint venture. If firms in an R & D joint venture cannot exclude rivals, then a partition of firms is an equilibrium if no firm in a joint venture can increase its expected value by defecting to the fringe or joining another joint venture, no group of firms in the fringe can increase their expected values by forming a joint venture, and no single firm in the fringe can increase its expected value by joining an R & D joint venture.[9]

A. R & D Reaction Functions

In a market of the type discussed in the previous section, suppose J firms form an R & D joint venture, while F fringe firms carry out independent R & D programs. If a firm in the fringe is the first to succeed, it obtains a monopoly in the use of the new

9. The latter concept is the same as the d'Aspremont, Jacquemin, Gabsewicz, and Weymark [1983] criterion of internal and external stability for output cartels.

technology. Other firms may continue to produce, using the old technology, if they find it profitable to do so. If any firm in the joint venture is the first to succeed, all firms in the joint venture have access to the new technology. Fringe firms may continue to produce, using the old technology, if they find it profitable to do so.

The value of a single fringe firm, say firm 1, is

(17) $$V_f^1 = \frac{\pi_C(c_1) - z(h_1) + \dfrac{h_1\pi_W^F + Jh_j\pi_L^J + (\sum_{i=2}^{F} h_i)\pi_L^F}{r}}{r + Jh_j + \sum_{i=1}^{F} h_i} .$$

π_W^F is the winner's payoff if the winner is in the fringe; π_J^L if a fringe firm's payoff if the winner is in the joint venture; and π_F^L is a loser's payoff if the winner is in the fringe.

The first order condition for maximization of V_f^1 defines fringe firm 1's research intensity reaction surface. In equilibrium all fringe firms will chose the same research intensity, h_f, which satisfies

(18) $$[r + Jh_j + Fh_f]\left[\frac{\pi_W^F}{r} - z'(h_f)\right] = \pi_C(c_1) - z(h_f) + \frac{[\pi_W^F + (F-1)\pi_L^F]h_f + Jh_j\pi_L^J}{r}$$

From (17) and (18), the equilibrium value of a fringe firm is

(19) $$V_f^* = \frac{\pi_W^F}{r} - z'(h_f) .$$

The value of a firm in the joint venture is

(20) $$V_j = \frac{\pi_C(c_1) - z(h_j) + \dfrac{Jh_j\pi_W^J + (\sum_{i=1}^{F} h_i)\pi_L^F}{r}}{r + Jh_j + \sum_{i=1}^{F} h_i}$$

The first-order condition for maximization of V_j defines the joint venture's reaction surface. In equilibrium, all firms in the joint venture chose a common research intensity h_j, that satisfies the first order condition

$$(21)[r + J_j + Fh_f]\left[J\frac{\pi_W^J}{r} - z'(h_j)\right] = \left[\pi_C(c_1) - z(h_j) + \frac{Jh_j\pi_W^J + Fh_f\pi_L^F}{r}\right]J .$$

From (20) and (21), the equilibrium value of a firm in the joint venture is

$$(22) \qquad V_j^* = \frac{\pi_J^*}{r} - \frac{z'(h_j)}{J}$$

Output, and therefore consumers' surplus, in the post-innovation market depends on whether or not the innovation is drastic.[10] Expected consumers' surplus is

$$(23) \qquad CS = \frac{b}{2}\,\frac{\left(\frac{J + F}{J + F + 1}S_1\right)^2 + \frac{Jh_j}{r}(Q_W^J)^2 + \frac{Fh_f}{r}(Q_W^F)^2}{r + Jh_j + Fh_f} .$$

Equilibrium research intensities h_f and h_j are determined by solving (18) and (21) as a system of simultaneous equations. If the R & D cost function is quadratic, (18) and (21) are equations of rotated hyperbolae, better suited to numerical than analytic solution.

B. Non-drastic Innovation

Table 2 describes equilibrium characteristics for different R & D structures a non-drastic innovation. For two firms, there are only two alternatives: each firm undertakes independent research and development, or both firms form a joint venture. If there are three

10. If a firm in the joint venture wins the race, the Cournot output of a fringe firm is $q_f = [(J + 1)S_1 - JS_2]/(J + F + 1)$. The innovation is J-drastic if this is negative, in which case the post-innovation market is a J-firm Cournot oligopoly. Otherwise the innovation is not J-drastic. See footnote 6 for the condition if a fringe firm wins the race.

Table 2: Relative market performance with partial joint ventures, non-drastic innovation

Relative market performance, rivalry vs. R & D joint venture

$p = 100 - Q$, $n = 2$, $c_1 = 50$, $c_2 = 40$, $z(h) = 1000h + 10{,}000h^2$, $r = 1/10$

	h	Mean	Firm value	CS	NSW
(0,2)	0.0865	5.78	2,715.04	6,294.78	11,724.85
(2,0)	0.0486	10.29	3,013.99	6,760.44	12,788.41
(0,3)	0.0772	4.32	1,455.45	7,707.93	12,074.27
(2,1)	h_j = 0.0867	3.81	V_j = 1,695.26	8,226.17	12,835.09
	h_f = 0.0891		V_f = 1,218.26		
(3,0)	0.0349	9.56	1,684.15	8,613.15	13,665.59
(0,0,4)	0.0666	15.02	908.03	8,596.20	12,228.31
(2,0,2)	h_j = 0.0929	2.99	V_j = 1,131.07	8,998.87	12,760.20
	h_f = 0.0745		V_f = 749.65		
(2,2,0)	0.1116	2.24	943.53	5,936.92	11,635.98
(3,0,1)	h_j = 0.0734	3.32	V_j = 1,137.34	9,582.14	13,619.94
	h_f = 0.0807		V_f = 625.78		
(4,0,0)	0.0252	9.90	1,063.75	9,768.7	14,023.75
(0,0,5)	0.0578	3.46	620.86	9,206.91	12,311.21
(2,0,3)	h_j = 0.0924	2.67	V_j = 825.87	9,526.40	12,722.64
	h_f = 0.0631		V_f = 514.83		
(3,0,2)	h_j = 0.0866	2.52	V_j = 866.93	10,031.13	13,451.49
	h_f = 0.0684		V_f = 409.79		
(4,0,1)	h_j = 0.0607	3.19	V_j = 807.40	10,564.15	14,160.96
	h_f = 0.0705		V_f = 367.20		
(2,2,1)	h_j = 0.1080	2.00	V_j = 669.72	9,800.98	12,899.97
	h_f = 0.0679		V_f = 420.12		
(3,2,0)	h_j = 0.1075	1.79	V_j = 727.79	10,280.02	13,614.64
	h_k = 0.1174		V_k = 575.62		
(5,0,0)	0.0182	11.02	727.39	10,497.76	14,134.73

Notes: last entry in each n-tuple is the number of fringe firms; earlier entries are number of firms in the R & D joint venture or joint ventures. Subscripts j and k denote values for joint ventures, subscript f denotes fringe values.

firms, there are three alternatives: completely independent R & D, completely joint R & D, or partial cooperation: an R & D joint venture of two firms, with one firm carrying out its own R & D program. When there are four or more firms, it is possible to have more than one joint venture, possibly with a fringe of independent firms.[11]

If there are two firms, it is net social welfare is greatest if both firms to form an R & D joint venture, and firms maximize their expected value by forming an R & D joint venture. This result is the same as the two-firm example of Table 1.

If there are three firms, it is again a complete R & D joint venture that produces the greatest net social welfare. If all firms form a joint venture, firm value is 1,684.15, which is greater than the value 1,455.45 that results from independent R & D. If two firms can form an R & D joint venture, they are even better off, with an expected value of 1,695.26 apiece. The fringe firm would have a lower value, however, than it would as a member of a three-firm R & D joint venture.

Hence if firms are unable to exclude rivals from an R & D joint venture, the market equilibrium structure of R & D is a three-firm joint venture. But if firms can exclude rivals from an R & D joint venture, the equilibrium result has two firms forming a joint venture, leaving one firm to carry out its own R & D project.

The case of four firms is similar to the case of three firms. There are five possible R & D structures. The best outcome of the these five is for all firms to form an R & D joint venture, and if exclusion is not possible, this is the market equilibrium structure.

11. Equilibrium R & D intensities for the latter cases are determined as for the cases considered explicitly in the text. Each joint venture or fringe firm maximizes expected value, taking the R & D intensities of other players as given, which yields a set of R & D reaction functions. Equilibrium research intensities are the solution of the equations of these reaction functions.

(For it to be otherwise, the value of a fringe firm under some configuration would have to exceed the value of a firm which is a member of a 4-firm R & D joint venture.) If firms can exclude rivals from an R & D joint venture, the equilibrium configuration has three firms form a joint venture, leaving one firm in the fringe.

If there are five firms, the best possibility is for four firms form a joint venture, while one firm carries out its own R & D project. When the number of firms is large, if all firms form a joint venture, per-firm research intensity falls to such a low level that it is better from a social point of view to have some firms undertake research on their own, even through this creates the possibility that only one firm will have access to the new technology in the post-innovation market.

If there are five firms and firms cannot exclude rivals from an R & D joint venture, the equilibrium structure has all firms forming a single R & D joint venture. But if firms can exclude rivals from a joint venture, the equilibrium structure is the socially optimal structure: four firms in a joint venture, one firm carrying out its own R & D program.

For non-drastic innovation, this example shows that some degree of cooperation in research and development is usually socially optimal. If the number of firms is small, it will be optimal for all firms to form a joint venture. If the number of firms is large, some partition of firms into joint ventures and a fringe will produce the greatest net social welfare under a market system. This structure of research and development is not likely to emerge as a market equilibrium if firms are able to exclude rivals from R & D joint ventures, particularly if the number of firms is small.

Table 3: Relative market performance with partial joint ventures, drastic innovation

Relative market performance, rivalry vs. R & D joint venture

$p = 100 - Q$, $n = 2$, $c_1 = 90$, $c_2 = 70$, $z(h) = 1000h + 10{,}000h^2$, $r = 1/10$

	h	Mean	Firm value	CS	NSW
(0,2)	0.0504	9.93	242.61	675.27	1,160.50
(2,0)	0.0299	16.71	200.69	887.92	1,289.31
(0,3)	0.0540	6.17	170.20	802.92	1,313.53
(2,1)	h_j = 0.0370	7.90	V_j = 130.38	1,038.11	1,494.59
	h_f = 0.0527		V_f = 195.71		
(3,0)	0.0194	17.21	100.02	1,108.23	1,408.30
(0,0,4)	0.0559	4.47	131.71	876.28	1,403.12
(2,0,2)	h_j = 0.0404	5.23	V_j = 96.43	1,091.08	1,576.12
	h_f = 0.0552		V_f = 146.09		
(2,2,0)	0.0392	6.38	108.42	735.03	1,168.72
(3,0,1)	h_j = 0.0246	7.88	V_j = 65.47	1,226.79	1,609.19
	h_f = 0.0531		V_f = 186.00		
(4,0,0)	0.0114	21.93	53.00	1,121.78	1,333.77
(0,0,5)	0.0571	3.50	107.77	923.27	1,462.10
(2,0,3)	h_j = 0.0423	3.93	V_j = 76.68	1,114.58	1,619.00
	h_f = 0.0566		V_f = 117.02		
(3,0,2)	h_j = 0.0272	5.20	V_j = 48.14	1,250.81	1,678.08
	h_f = 0.0554		V_f = 141.42		
(4,0,1)	h_j = 0.0153	8.76	V_j = 33.48	1,263.50	1,588.51
	h_f = 0.0529		V_f = 191.10		
(2,2,1)	h_j = 0.0416	4.49	V_j = 83.95	1,335.36	1,799.61
	h_f = 0.0561		V_f = 128.46		
(3,2,0)	h_j = 0.0262	6.32	V_j = 54.00	1,521.95	1,890.86
	h_k = 0.0397		V_k = 103.46		
(5,0,0)	0.0049	40.45	30.22	897.82	1,048.94

Note: last entry in each n-tuple is the number of fringe firms; earlier entries are number of firms in the R & D joint venture or joint ventures. Subscripts j and k denote values for joint ventures, subscript f denotes fringe values.

The divergence between market and optimal structures will be even greater if the innovation is drastic, as shown in Table 3. In every case shown in Table 3, it is optimal for there to be some degree of cooperation in research and development. But for every case reported in Table 3, and whether or not firms are able to exclude rivals from an R & D joint venture, the market equilibrium has firms carry out independent R & D programs.

These examples make clear that the socially optimal market structure for the organization of research and development activity is a complex phenomenon, depending on the number of firms and the magnitude of the expected innovation. These examples suggest two policy conclusions. First, a legal regime that denies firms the right to exclude rivals from an R & D joint venture will usually lead to better market performance, in an expected social welfare sense, than a legal regime that permits such exclusion. Second, and particularly for drastic innovation, it will not be enough for government to permit firms to voluntarily form R & D joint ventures: government will have to induce the formation of socially beneficial R & D joint ventures that will often not be privately profitable.

V. Production Joint Ventures[12]

There are many cases in which joint ventures combine the operations of two or more actual competitors. Such joint ventures have historically been common in Europe, as a way of crossing national boundaries (Bayer [1982]). The same phenomenon appears to be replicating itself on a worldwide basis, at least in particular industries (Holusha [1988]; see also Bresnahan and Salop's [1986] discussion of a joint venture between General Motors and Toyota [1986]). Given the increasing importance which is attached to

12. See Reynolds and Snapp [1986] and Bresnahan and Salop [1986] for related treatments.

international competition as a way of promoting acceptable market performance, it is important to understand the implications of such joint ventures.

In this section I examine the consequences for market performance of a legal regime which permits firms that have formed an R & D joint venture to create an independent subsidiary - a production joint venture (PJV) - to use the new technology once innovation has taken place. I suppose that parent firms may continue to produce, using the old technology, if they find it profitable to do so. The production joint venture maximizes its own profit, taking the outputs of parent firms as given.

The specification of independent behavior by parent firms may seem unrealistic or unlikely. Two comments are in order. First, there are few public policy questions about production joint ventures which are vehicles for coordinated behavior. If parent firms use a production joint venture to maximize joint profit, market behavior is collusive, the joint venture will harm consumers, and whether or not the joint venture is socially beneficial depends on the tradeoff between benefit to producers and harm to consumers. This tradeoff is analyzed by Williamson [1968, 1977].

Second, independent behavior will often be mandated by policy requirements. An example is provided by a European Commission decision which permitted a joint venture between an American company and a European company (**In re DeLaval-Stork**[13]), imposing restrictions

13. Commission Decision of 25 July 1977.

designed to ensure the ability of the parent firms to compete after the formation of the joint venture.

A. The Post-Innovation Regime with a Production Joint Venture

Once innovation has occurred, the production joint venture (PJV) maximizes its own profit, taking the outputs of parent firms as given. Its profit is

$$\pi_{pjv} = \left[a - c_2 - b\left(\sum_{i=1}^{n} q_i + q_{pjv} \right) \right] q_{pjv}$$

(24)

$$= b\left(S_2 - \sum_{i=1}^{n} q_i - q_{pjv} \right) q_{pjv} .$$

Taking note of the fact that in equilibrium all parent firms will produce the same output (q), the first-order condition for maximization of (24) yields the PJV output reaction function,

(25) $$nq + 2q_{pjv} = S_2 .$$

Each parent firm independently maximizes its payoff,

(26) $$G_i = \pi_i + \frac{1}{n}\pi_{pjv} ,$$

where the first term on the right is the firm's profit using the old technology and the second term is the firm's share of the profit of the production joint venture. Maximization of (26) yields the output reaction function

(27) $$(n + 1)q + \frac{n + 1}{n} q_{pjv} = S_1 .$$

Solving (25) and (27), we obtain equilibrium outputs

(28) $$q = \frac{2S_1 - [(n + 1)/n]S_2}{n + 1} \qquad q_{pjv} = \frac{(n + 1)S_2 - nS_1}{n + 1}$$

For this discussion, I assume that the innovation is non-drastic, so that q from (28) is positive.

From (28), total output after innovation is

(29) $$\frac{n}{n+1}S_1 ,$$

which is the equilibrium output of the pre-innovation market. With a production joint venture, price, output, and consumers' surplus will be the same, before and after the innovation.

Parent firms, however, are better off because of the production joint venture: each parent firm inherits its share of π_{pjv}. Not only do parent firms receive a greater profit after innovation, but they earn a greater profit with a production joint venture than they would if each parent firm competed as a Cournot oligopolist using the new technology:[14]

(30) $$G_1 - \pi_C(c_2) = \frac{b}{(n+1)^2}\left\{ S_1\left[2S_1 - \frac{n+1}{n}S_2 \right] + n(S_2 - S_1)\left[(n+2)S_2 - nS_1 \right] \right\} > 0 .$$

It follows that parent firms will prefer to set up a production joint venture to use the new technology, if they are able to do so.

B. R & D Investment with a Production Joint Venture

The expected value of a parent firm is

(31) $$V_p = \frac{\pi_C(c_1) - z(h_p) + \frac{nhG_1}{r}}{r + nh_p} .$$

This has the same form as (13), substituting G_1 for Cournot profit $\pi_C(c_2)$. Since equilibrium R & D effort is an increasing function

14. The first term in brackets on the right is positive so long as parent firms have positive output in the post-innovation regime; all other terms on the right are positive.

of the post-innovation payoff,[15] it follows that parent firms will invest more in R & D if they are able to form a production joint venture than under an R & D joint venture with independent use of the new technology in the post-innovation market.

A production joint venture therefore increases investment in R & D, increases the expected value of parent firms, and shortens the expected waiting time to successful innovation. But it also denies consumers the benefits that would flow from rivalry in the use of the new technology.

Table 4: Comparison of independent R & D, complete R & D joint venture, and complete production joint venture

$p = 100 - Q$, $c_1 = 50$, $c_2 = 40$, $z(h) = 1000h + 10{,}000h^2$, $r = 1/10$

	n	h	Mean	Firm value	CS	NSW
Ind	2	0.0865	5.78	2,715.04	6,294.78	11,724.85
RDJV	2	0.0486	10.29	3,013.99	6,760.44	12,788.41
PJV	2	0.0541	9.25	3,070.28	5,555.56	11,696.11
Ind	3	0.0772	4.32	1,455.45	7,707.93	12,074.27
RDJV	3	0.0349	9.56	1,684.15	8,613.15	13,665.60
PJV	3	0.0393	8.48	1,717.07	7,031.25	12,182.45
Ind	4	0.0666	3.75	908.03	8,596.20	12,228.31
RDJV	4	0.0252	9.90	1,063.75	9,768.73	14,023.75
PJV	4	0.0309	8.09	1,095.49	8,000.00	12,381.97
Ind	5	0.0578	3.46	620.86	9,206.91	12,311.21
RDJV	5	0.0182	11.02	727.39	10,497.76	14,134.73
PJV	5	0.0255	7.86	759.27	8,680.56	12,476.90

15. Writing R for the post-innovation payoff in (14) and differentiating, we have

$$\frac{\partial h}{\partial R} = \frac{1}{z''(h)} \frac{n}{r + nh} > 0 .$$

Table 4 compares equilibrium results for a modest innovation with 2 to 5 firms for independent R & D, a complete R & D joint venture, and a production joint venture. Among these three alternatives, net social welfare is maximized by a complete R & D joint venture, but firm value is maximized by a production joint venture. Private and social incentives for the organization of research, development, and production diverge. While R & D joint ventures will usually be socially beneficial, production joint ventures do not appear to be a socially desirable way to organize the use of new technology.

VI. Final Remarks

The examples considered in this paper show that R & D joint ventures are, generally, desirable from a social point of view. This desirability has nothing to do with the impact of the joint venture on R & D activity. Indeed, the effect of an R & D joint venture is to reduce investment in R & D and delay the expected time to successful innovation. R & D joint ventures have a positive effect on expected net social welfare because they ensure rivalry in the use of the new technology, once it is discovered.

If there are economies of scale or scope in research and development, then an R & D joint venture will increase expected net social welfare because it increases the productivity of the R & D process. Such effects are ruled out by assumption in the model considered here, but if they occur they will make R & D joint ventures even more beneficial than appears from the present analysis.

In the model presented here, R & D joint ventures are socially beneficial because they ensure competition in the post-innovation market. If, as often suspected, cooperation in R & D facilitates noncooperative collusion in output decisions, then the beneficial welfare effect of joint R & D will fail to materialize. This conclusion is supported by the analysis of production joint ventures for the use of a new technology. Such PJVs are privately profitable for parent firms, but deny consumers the benefits which flow from competition in the use of a new technology, and reduce net social welfare.

The optimal structure of cooperative R & D is a complex phenomenon, resulting from a tradeoff between the hope for profit that will result from successful R & D if the right to use the new technology is limited and the expected consumers' surplus that results if the right to use the new technology is not limited. If R & D joint ventures are permitted, there is no reason to think that the structure of R & D cooperation that emerges when firms maximize their expected value will yield the greatest net social welfare possible under a market system.

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