Distorting the direction of technological change

William James Adams [a]*, David Encaoua [b]

[a] *Department of Economics, University of Michigan, Ann Arbor, MI 48109-1220, USA*
[b] *University of Paris 1, Paris, France*

Abstract

This article explores a monopolist's incentive to distort the direction of technological change. For strategic reasons, the monopolist might invent and employ a socially undesirable technology. In so doing, he might jeopardize not only the vigor of product–market competition but also the development of socially desirable methods of production. As a result, technological dynamism cannot be considered a social virtue until its direction is compared with the social optimum.

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JEL classification: L1; O3; L41

1. Introduction

How should one attempt to measure the effects of innovative monopoly on social welfare? If the monopolist innovates in a socially desirable manner but prices his product inefficiently, then his conduct can be appraised as in Williamson (1968). But what if the monopolist's innovations actually diminish social welfare? What if their profitability stems less from their intrinsic effects on the monopolist's cost and product than from their disadvantageous effects on his actual and potential rivals?

Strategic innovation might affect the timing and/or the content of technological change. To date, the theoretical literature on strategic innovation has focused on timing rather than content (Reinganum, 1989). Except in the study of sleeping patients (Gilbert and Newbery, 1982), the direction of technologi-

cal change has been largely ignored. To understand the significance of this neglect, consider the technological performance of the American Telephone and Telegraph Company. Before its fragmentation in 1984, AT&T was frequently praised as a good monopolist whose scientific laboratories contributed many of the major discoveries associated with its lines of business. Without questioning the quantity, celerity, or prodigy of AT&T's research efforts, however, one might still wonder whether a firm in its position might experience incentives to perform the wrong type of research (from society's point of view).

In this article, we demonstrate that a monopolist might consciously forgo development of a socially desirable technology in order to develop and utilize a socially undesirable alternative. In so doing, he effectively prevents development of the socially desirable technology. From his perspective, development of the socially desirable technology fails to maximize profit because it permits the emergence of competition in his product market. He finds it more profitable to develop an inferior technology for use in a monopolized market than to develop a superior technology for deployment in a shared market.

After describing our model (Section 2) and presenting a numerical example of the strategic behavior it is designed to illustrate (Section 3), we discuss (Section 4) some of the many ramifications of recognition that powerful firms might find it profitable to distort the direction of technological change.

2. The model

The strategic incentive to orient technology can be analyzed quite instructively using the model developed for other purposes by Dixit (1980). Our model diverges from that of Dixit in one important respect: Rather than limit arbitrarily the number of potential competitors to one, we allow profit-expectations to determine the number of firms that enter the market in response to incumbent behavior.[1]

Given our focus on the direction of technological change, we represent production cost in a manner that includes more than one parameter. It is the existence of multiple cost parameters that opens the possibility that strategic incentives prompt a firm to modify the wrong parameters, or even tó modify the right parameters in the wrong directions.

We have investigated several different formulations of production cost. Our favorite is the U-shaped average cost curve

$$C(Q)/Q = (Q - (a + g))^2 + (b - h)Q, \tag{1}$$

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[1] The consequences of endogenizing the number of entrants will become apparent in note 10.

in which a, g, b, and h are parameters (Adams et al., 1992). In this specification, $(a+g)$ represents the rate of output that minimizes unit cost and $(b-h)$ represents the minimum attainable value of unit cost. Technological change can increase the rate of output that minimizes unit cost (by increasing g) or lower the minimum attainable value of unit cost (by increasing h).

In order to simplify our model to the utmost, however, we forsake Eq. (1) and adopt Dixit's decomposition of total cost into additively separable fixed and variable elements. Despite its simplicity, and unlike the even simpler alternative in which total cost varies proportionately with output, Dixit's representation of production cost does not preclude by assumption the strategic interest of a monopolist in developing and using technologies that raise fixed cost and lower marginal cost in socially undesirable ways.

2.1. Technological change

The total cost of production in each period is

$$C(Q) = f + cQ, \tag{2}$$

where f and c are parameters and Q is the rate of output. Technological change alters the parameter-values, but not the form, of the cost function. Technological change involves two distinct types of activity: first research, then development. Research is undertaken noncommercially (i.e., exogenously with respect to business enterprises) and generates scientific progress. Enterprises then convert scientific knowledge into commercial technology by engaging in the process of development.

Realistically speaking, development of a new technology from a given stock of scientific knowledge depends on many factors, including the complexity of the science and the technology, the amount of money spent, the amount of time taken, the developer's stock of technological expertise, and luck. In this article, we emphasize the importance of technological expertise. In our view, it is often plausible to suppose that relatively great experience in the relevant industry permits a firm to develop a new production technology at relatively low cost (given speed), or relatively quickly (given cost).[2] We shall represent the advantage of experience in terms of project-speed, ignoring project-cost in the process.

Specifically, we model technological change as follows: Once the stock of

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[2] To the extent, however, that a new technology requires a radical break with established practice, experienced firms could face a cost- or speed-disadvantage in its development.

scientific knowledge contains the requisite information, any firm can develop a new technology (T_i) with certainty by spending a known sum of money (R_i).[3] Although all firms discover scientific advances simultaneously, they differ regarding the amount of time that must elapse between revelation of scientific advance and commitment to develop the corresponding technology: The greater the firm's experience, the more quickly it can effect the commitment. Thus firms choose their development strategies sequentially. We assume that each firm commits to a development strategy with full knowledge of all commitments already made by prior technological movers.

Technological expertise is enjoyed more by incumbents than by potential competitors. Therefore, technological commitments can be achieved sooner by the former than by the latter. Depending on the diversity of their experience, particular incumbents might also encounter advantage or disadvantage vis-à-vis one another. Whatever the relationship among the incumbents, however, potential competitors are heterogeneous in technological expertise.[4] As a result, in the spirit of Bain, they form a queue, not a pool, of firms contemplating technological development. The most advantaged potential competitor chooses his technological path immediately after the (least advantaged) incumbents. Following him comes the second in line. The process of technological development stops when no additional potential competitor finds it profitable to develop any of the technologies permitted by the stock of scientific knowledge.

Note that nothing prevents two or more firms from developing and utilizing the same technology. In effect, we assume that patents do not prevent replication of a specific technology.[5] Note also that although more than one firm can develop and utilize a given technology, each must pay to do so: No firm can free-ride financially on the development activities of others.

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[3] We have also explored more general formulations of the relationship between a firm's development expense and its transformation of production cost (Adams et al., 1992). For example, in the context of the average cost curve in Eq. (1), we have specified the relationship between R and the change in production cost as the convex function $R(g, h) = sg^2 + th^2$, where s and t are research cost parameters, and g and h are the production cost parameters that are altered via technological development. In this formulation, the more a firm spends on technological development, the more it changes its production cost parameters – subject to diminishing returns to research expenditure.

[4] Some potential competitors may be established already in other industries. These may enjoy more technological expertise than do firms not yet established in any industry. Vis-à-vis each other, however, they may enjoy more or less (relevant) expertise, depending on the industries in which each has acquired its experience.

[5] Patent infringement might be difficult to establish at law; or the penalties for infringement might be too slight to deter the practice. No matter how effectively patents are protected in the legal sense, scientific progress might create so many paths along which a given new technology can be introduced that developers run no risk of infringing each other's patents.

2.2. The product market

Market price is determined by

$$P = d - eQ, \tag{3}$$

where d and e are parameters and Q is the number of units (produced and) sold. The inverse demand function is known to all competitors, actual and potential.

A firm cannot supply the market unless it has already developed and deployed the technology it plans to use. At the time it selects its output, each firm knows the number and the technologies of its rivals. We assume that product-market behavior generates a Cournot–Nash equilibrium in pure strategies.

2.3. The sequence of events

Each period of time includes the following sequence of events: First the current stock of scientific knowledge is revealed to all firms. Then the first technological mover makes his technological commitments: First he decides which feasible technologies, if any, to develop; he does so by committing to pay the relevant one-time, technology-specific fees. Then he decides which technologies, if any (among those he has developed) to deploy for use in production; he does so by committing to pay the relevant period- and technology-specific fixed cost of production. Then, with full knowledge of the first-mover's technological decisions, the second-mover makes his own technological commitments. And so on. The period ends with a Cournot–Nash equilibrium in the product market.

The model consists of two periods.[6] The periods differ in terms of scientific opportunities. Our principal goal is to compare the second-period product-market equilibrium to some normative benchmark. Our benchmark is the outcome that generates the largest amount of social surplus while satisfying the model's behavioral assumptions.[7]

3. A numerical example of strategic invention

In this section, we establish by numerical example an incumbent mono-

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[6] We assume a discount rate between periods of 0.

[7] Social surplus is the sum of producer and consumer surplus. Note the difference between our normative benchmark and one constrained only by scientific opportunities and consumer tastes. For example, marginal cost pricing by a monopolist could constitute the latter benchmark, but not the former.

Table 1
Parameter values

Technology	Parameter		
	f	c	R
T_1	25	8	1.00
T_2	22	7	1.01
T_3	30	6	13.00

polist's incentive to deter entry by developing and utilizing a socially undesirable technology.

Consider a new market devoid of incumbents in which the demand parameters of Eq. (3) are $d = 22$ and $e = 1$. Suppose that the state of scientific knowledge permits development of just one technology (T_1 in Table 1) during period 1.

Monopoly in the product market would result in profit of 23. Cournot rivalry between two or more sellers would result in negative profit for each. As a result, given the sequential and informed nature of technological commitment, one and only one firm develops and utilizes T_1.

Now suppose that scientific progress permits development of two additional technologies (T_2 and T_3 in Table 1) during period 2.[8]

The incumbent from period 1 moves first in the second round of technological development. In choosing his technological response to scientific progress, he anticipates the technological reactions of potential competitors to his own technological choice. If the incumbent develops neither new technology, the most advantaged potential entrant develops and utilizes T_2, and the incumbent exits the product market (see Table 2). If the incumbent develops T_2, the most advantaged potential entrant also develops T_2, and each realizes profit of 2.[9] If, however, the incumbent develops T_3, no potential competitor develops any technology; the incumbent's monopoly is

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[8] We deliberately make one technology substantially more costly to develop than are the other two. Our purpose is to demonstrate how strategic incentives can induce a firm to develop relatively costly technology despite its social inferiority and despite the ease with which the socially preferred alternative can be developed subsequently by potential rivals. Strategic distortion does not, however, depend on such asymmetry in development cost [Adams et al. (1992)]. Nor does such asymmetry depend on ad hoc choices of R: The three values of R in Table 1 satisfy the linear research cost function $R(f, c) = \max(0, gf - hc)$, with $g = (49/45)$ and $h = (59/18)$.

[9] The second firm in the queue of potential competitors chooses not to enter the business. From its perspective, the best entry option is T_2 triopoly, which confers profit of -9 on each seller.

Table 2
Payoff matrix in period 2[a]

Firm I	Firm II			
	T_0	T_1	T_2	T_3
T_0	0, 0	0, 23	0, 33	0, 21
	(0)	(48)	(61)	(53)
T_1	24, 0	−3, −4	−6, 5	−9, −7
	(49)	(36)	(46)	(34)
T_2	33, 0	5, −7	2, 2	−1, −11
	(61)	(45)	(54)	(41)
T_3	21, 0	−7, −10	−11, −1	−15, −15
	(53)	(33)	(41)	(28)

[a]Firms I and II are the incumbent and the most-advantaged potential competitor, respectively. For firm II, T_0 represents the decision not to develop any of the three technologies. For Firm I, T_0 represents the decision neither to use T_1 nor to develop T_2 or T_3. Profits are net of development expenses incurred in period 2. Numbers in parentheses are social surpluses (sums of consumer and producer surplus). Numbers are rounded to the nearest integer.

sustained, permitting him to realize 21 in profit. Clearly, the monopolist develops and utilizes T_3.[10]

The decision to develop and utilize T_3 is definitely strategic. If protected somehow from competition, regardless of his technological choice, the monopolist would develop T_2. The profitability of developing and utilizing T_3 stems from its effect on the behavior of potential competitors.

In this example, then, although strategic considerations fail to alter the *amount* of technological change (over the two periods, two new technologies are developed whether or not the incumbent is protected exogenously from competition) or the *pace* of technological change (in both cases, one new technology is developed in each period), they do alter the *direction* of

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[10] Before concluding that the monopolist develops and utilizes T_3, one must understand why the incumbent does not pursue the alternative strategy of developing T_2 and then bribing the potential entrant (in the amount of 2 plus epsilon) not to develop T_2. Such a strategy might seem to result in greater profit (33-2-epsilon) than does T_3 monopoly. Bribery is unprofitable in this example, however, as long as potential entrants are numerous and ranked. As long as the second-most-advantaged potential entrant knows, at the time he makes his technological choice, that the most advantaged potential entrant will not actually supply the product market, this second potential entrant will find it profitable to develop T_2 in response to the incumbent's selection of T_2. As a result, the incumbent will have to bribe two potential competitors, not one. This process will continue indefinitely, making bribery in this form less profitable than strategic invention of T_3. In this particular example, only if the number of potential competitors is smaller than seven will the incumbent's preferred strategy consist of bribery cum development of T_2.

technological change (T_3, not T_2, is developed in period 2 if the incumbent is not protected exogenously from competition).

Notice that the incumbent's choice of technology depends critically on the existence of his first-mover advantage. If the incumbent and one potential entrant choose their technologies simultaneously (the rest choosing later on), the unique Nash equilibrium (in pure strategies) is T_2 duopoly. We shall return to the assumption of first-mover advantage in Section 4.[11]

From a normative perspective, within the payoff matrix of Table 2, the preferred technology is T_2 and the preferred market structure is monopoly. Nevertheless, society has a greater stake in the optimal technology than it does in the optimal market structure, for T_2 duopoly generates more social surplus than does T_3 (or T_1) monopoly.[12] The strength of society's preference for T_2 can be attributed to the cost of developing T_3.

4. Discussion

We have confined ourselves in this article to the presentation of one numerical example within a simple but carefully motivated model. On the basis of work we report elsewhere (Adams et al., 1992), employing a model of some generality, we believe that incentives to distort the direction of technological change do not arise solely in exotic and ad hoc configurations of parameter-values. Let us consider, therefore, some implications of our findings and a possible extension of our framework.

1. *Technological progress and social welfare.* Schumpeter believed that market structure is a major determinant of technological progress. His view has received considerable empirical scrutiny. Operationally, this scrutiny consists of measuring the effects of market structure on the amount of research undertaken and the amount of discovery achieved. To the extent that the incentives explored in this article do affect the behavior of real enterprises, such evidence requires careful interpretation. Firms positioned to behave strategically might spend bountifully on R&D, develop radically new technologies, and innovate rapidly; in so doing, however, they might simply

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[11] Before leaving the situation involving two first movers in period 2, let us note one of its implications. We have assumed in effect that firms cannot predict the evolution of science. Suppose instead that all firms enjoy perfect scientific foresight. If the second mover in period 1 develops T_1 in period 1, then he loses 4 in period 1 but shares first mover advantage in period 2. This results in profit for him of 2 in period 2. Since his loss in period 1 exceeds his prospective profit in period 2, the second mover decides not to develop T_1 in period 1. In other words, in this example, even if all firms enjoy perfect scientific foresight, the first mover finds it profitable to distort strategically the direction of technological change.

[12] If the number of sellers using T_2 exceeds 2, however, the result is socially inferior to T_3 or T_1 monopoly. For example, T_2 triopoly generates social surplus of 36.

be engaged in strategic suppression of technologies which better serve the public interest. To merit normative content, evidence on the relationship between market structure and inventive activity cannot be examined, as it currently is, without considering the impact of the inventive activity on the direction of technological progress.

2. *Technological progress and antitrust policy.*   Antitrust enforcers on both sides of the Atlantic display considerable reluctance to attack, convict, or punish firms that enjoy a reputation for inventive prowess [compare Jorde and Teece (1992)]. After all, such firms might owe their powerful positions to 'superior skill, foresight, and industry', and the public interest dictates that '[t]he successful competitor, having been urged to compete, must not be turned upon when he wins'.[13] The remedies administered to such firms often reveal the enforcer's fear that promotion of competition in the product market might jeopardize invention in the research laboratory. No prosecutor or judge wants to be known as the person who extinguished innovation in a sunrise industry.

Our example suggests that antitrust enforcers should avoid indiscriminate veneration of innovation. Not all technological development serves the public interest. Where powerful firms enjoy strategic incentives to distort the direction of technological change, vigorous enforcement of the antitrust laws may curtail certain kinds of innovative activities; in so doing, however, it might ensure that technological change proceeds in a socially desirable direction.

3. *Vertical integration and market power.*   We have assumed that product-market incumbents enjoy first-mover advantage in technological development. In our numerical example, this advantage proved critical to the incumbent monopolist's strategy of technological orientation.

The inventions discussed in this article generate new production technologies, not new products. To the extent that technologies are embodied in capital equipment, and to the extent that users buy their equipment from independent suppliers, it seems plausible to suppose that firms established in the equipment business possess at least as much (relevant) technological expertise as do users of that equipment. However reasonable it is to suppose that incumbent users of equipment enjoy first-mover technological advantage vis-à-vis their potential competitors, it may be unreasonable to suppose such advantage vis-à-vis producers of their capital equipment.

If makers and users of capital equipment share first-mover advantage in technological development, then might a downstream monopolist experience a strategic incentive to integrate backward? By making all of his own

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[13] The language is that of Judge Learned Hand in *United States v. Aluminum Co. of America et al.*, 148 F.2d 416, 430 (1945).

equipment, he might be able to avoid sharing his first-mover advantage in technological development. If so, vertical integration would enhance his power in a manner yet to be discussed in the economics literature.[14]

4. *Regulation and innovation.*   We have accorded all competitors the legal freedom to develop technologies and supply the market as they please. And yet, such freedom is quite implausible in the present context: Although economic regulation impinges on a small and shrinking set of activities, it remains relevant to industries smacking of natural monopoly – the very industries to which our model applies.

Moreover, from a normative perspective, it might seem as if the technological distortion occurring in our example can be resolved quite easily by subjecting the industry to economic regulation. By prohibiting entry, the civic-minded regulator remedies the private inability to sustain a socially desirable monopoly. In so doing, he induces the incumbent monopolist to develop and utilize the socially desirable technology.

Unfortunately, economic regulation does not always work so effectively. In fact, as the nonstrategic literature on regulation already suggests (Averch and Johnson, 1962), regulation can become a source in its own right of technological distortion. Might the difficulties of implementing socially desirable regulation be compounded by strategic incentives similar to those analyzed here? For example, might an incumbent monopolist with first mover advantage be able to convince his regulator to deny other firms the right to enter his market – even if the regulator attempts to maximize social surplus, the entrants propose to use socially desirable technology, the incumbent proposes to use socially undesirable technology, and the socially optimal number of sellers exceeds one? Such a question can be answered only within a model that provides explicit characterizations of how the regulator's behavior affects the monopolist and of how the monopolist's behavior affects the regulator. We plan to offer such a model, based on incomplete and asymmetric information, in another paper.

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[14] Note the significance of this argument in the context of the 1974 antitrust proceeding against AT&T. The U.S. Department of Justice argued initially that AT&T should be required to relinquish control of its manufacturing operations. It justified its position by citing the ability of a vertically integrated firm to use artificial transfer pricing to avoid effective regulation of its downstream activity. The integration incentive we discuss in the text exists whether or not the firm is regulated and whether or not regulators can prevent artificial transfer pricing.

References

Adams, W.J., B. Crépon and D. Encaoua, 1992, Choix technologiques et stratégies de dissuasion d'entrée, Economie et Prévision 102–103, 27–36.

Averch, H.A. and L.L. Johnson, 1962, Behavior of the firm under regulatory constraint, American Economic Review 52, 1052–1069.

Dixit, A., 1980, The role of investment in entry deterrence, Economic Journal 90, 95–106.

Gilbert, R.J. and D.M.G. Newbery, 1982, Preemptive patenting and the persistence of monopoly, American Economic Review 72, 514–526.

Jorde, T.H. and D.J. Teece, eds., 1992, Antitrust, innovation, and competitiveness (Oxford University Press, Oxford).

Reinganum, J.F., 1989, The timing of innovation: Research, development, and diffusion, in: R. Schmalensee and R. Willig, eds., Handbook of industrial organization, Vol. 1 (North-Holland, Amsterdam) 849–908.

Williamson, O.E., 1968, Economies as an antitrust defense: The welfare tradeoffs, American Economic Review 58, 1372–1376.