THE ECONOMIC AND SOCIAL RESEARCH INSTITUTE

GROWTH, THE MARKET AND DISSEMINATION OF TECHNOLOGY

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TWENTY SECOND GEARY LECTURE, 1991

Copies of this paper may be obtained from The Economic and Social Research Institute (Limited Company No. 18269). Registered Office: 4 Burlington Road, Dublin 4, Ireland.

Price IR£5.00
ISBN 0 7070 0132 3

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*Growth, the Market and Dissemination of Technology**

> The bourgeoisie ... has accomplished wonders far surpassing Egyptian Pyramids, Roman aqueducts and Gothic Cathedrals ...
>
> [It] cannot exist without constantly revolutionizing the instruments of production ... during its rule of scarce one hundred years [it] has created more massive and more colossal productive forces than have all preceding generations together (Marx [1847,1936, pp. 487-89]).

Karl Marx would surely be amazed at the evaluation of the market mechanism offered by today's mainstream economics. Received theory, its static welfare analysis culminating in the Arrow - Debreu theorem, emphasizes the efficiency of the market's allocation of resources absent monopolistic influences, externalities and government interference. That is, it tells us that labour, energy, and raw materials will be apportioned among the economy's tasks in precisely or very nearly the amounts needed to promote the welfare of consumers with maximal effectiveness. In contrast, when it comes to *growth* of output capacity, the standard theory leads us to suspect that the performance of the market will be mediocre or even worse than that. Research and development and other portions of the innovation process will suffer from underinvestment because of the spillovers of innovation – the fact that much of its benefits go to persons other than those who have borne the costs. The theory all but ignores another component of growth, the dissemination of new technology, except to imply that innovative business firms will do

*I am very grateful to the Price Institute for Entrepreneurial Studies, the Alfred P. Sloan Foundation and the CV Starr Center for Applied Economics at NYU for their generous support of this work.

In dealing with analysis intended to be applicable to reality, this paper follows the predispositions of Robert Charles Geary, the distinguished man whom I am honoured to be able to honour. He has been described as Ireland's greatest statistician. But his mind ranged too widely for that to be an accurate description of his achievements. As my countrymen would put it – his is indeed a hard act to follow. But I will do my best.

everything they can to impede it, by secrecy, use of patent protection and other means.

Marx would probably have made some typically acerb comments about these judgements because to him the dynamism of the capitalist economy was its prime virtue. It is ironic that this view is surely shared by the leaders of the East European nations who look to the market mechanism as the instrument of economic expansion that will save them from the poverty to which they believe they were condemned by central government direction.

This paper deals with one side of the matter – the dissemination of technology. Three main conclusions will be drawn: (1) Technology dissemination is a primary contributor to productivity growth, not only in the countries that are the beneficiaries of other nations' inventions, but in the world as a whole; (2) the market mechanism does not always reward firms that succeed in preventing others from sharing their new knowledge – on the contrary it may systemically and severely penalize failure to share and, thus, it can systemically *enforce* widespread exchange of technological information; (3) while it seems widely believed that enhancement of technology diffusion discourages innovative activity by facilitating the parasitical role of the free riders who benefit without sharing the costs, here reasons will be offered indicating that the market's pressures for technology exchange incidentally serve to reward and encourage investment in innovation.

This, then, would appear to be a rather heterodox view of the market's role in technology transfer and the importance of transfer for economic growth. The analysis may help to account for the remarkable, indeed, historically unprecedented performance of the free enterprise system, not as a means to elicit static efficiency, but as an instrument of growth.

I The Imitator's Place in the Standard Model of Innovation

Joseph Schumpeter's model deservedly remains the prime theoretical exploration of the innovation process. In that model the successful innovator introduces a better product or a less-costly production process. This enables her to beat out rivals and acquire some market power, bringing a temporary influx of monopoly profit that serves as the incentive for further investment in innovation. These profits persist until the innovator's laggard competitors finally learn the secrets of the new technology and succeed in introducing effective substitutes for the new products or processes. At that point all further benefits are transferred from the innovator to the general public, in the form of better goods and lower prices.

Two implications of this standard model are pertinent for us. First, the imitator – the agent of technology diffusion – does serve a valuable social purpose in Schumpeter's scenario, by terminating monopoly profits and transferring all further benefits of invention to the consuming public. But there seems to be no way in which the imitator contributes dynamic vitality to the economy; on the contrary, by holding down the innovator's reward he may impede economic expansion. Second, the model implies that the profit-seeking innovator will do everything in her power to prevent the dissemination of her proprietary technological information.

I will argue that both of these inferences are misleading. First, I will argue that imitation makes a vital contribution to the dynamics of an economy. Second, I will argue that the market often, indeed perhaps characteristically, provides powerful incentives for firms to share their innovations.

II The Vital Contribution of Imitation

In the sixteenth century when the Low Countries snatched economic leadership from Italy, these nations built their prosperity partly on ideas acquired from the Italians – banking techniques, cloth making processes and other products and methods were imitated in The Netherlands. A century later, as the British were pulling ahead, they learned canal building, architecture, engineering and other such skills from the Dutch. The Americans in turn learned steam transportation, metallurgy and many other forms of technology from the United Kingdom. Japan was hardly the first country to profit by imitation, though as we shall soon see, the borrower view of Japanese performance is itself a bit misleading.

It is clear that a recipient country is apt to benefit from technology transfer. But there is more to the story. We are *all* borrowers and none of us to an inconsiderable degree. Beyond that, it is very likely that we *all* grow far faster as a result of our learning from others

In a world of rapidly evolving technology it is remarkable and yet patently true that the industrial countries stay nearly abreast of one another in the technology they use. Products such as automobiles and computers from different lands come with similar features and their production makes common use of robots, and "just-in-time" inventory procedures. This means that engineers and managements must learn rapidly from one another and rapidly put what they learn into practice. It is not only smaller economies or more imitative economies that learn from the others.

Table 1 provides illustrative patent statistics. Reams have been written about the imperfection of patent data as measures of the volume and relative importance of

Table 1: *Patents Issued to Residents OECD Countries, 1988*

Country	*Total Patents*	*Patents/Population (millions)*	*% Held in Other OECD Countries*
Japan	47,912	391	64.0
USA	40,497	165	69.5
West Germany	15,704	258	88.2
France	8,822	158	93.4
UK	4,447	78	96.7
Switzerland	2,995	454	97.7
Italy	2,787	49	97.9
Sweden	2,424	289	98.2
Austria	1,364	180	99.0
Canada	1,184	45	99.1
Australia	988	61	99.3
Spain	909	23	99.3
Finland	776	157	99.4
The Netherlands	720	49	99.5
Denmark	344	67	99.7
Norway	277	66	99.8
Belgium	245	25	99.8
New Zealand	240	72	99.8
Greece	177	18	99.9
Luxembourg	76	208	99.9
Turkey	54	1	100.0
Ireland	10	3	100.0
Portugal	10	1	100.0
Iceland	0	0	100.0

Source: World Industrial Policy Organization (1989).

inventions. We will soon take note of an example of the distortion such figures may contribute if interpreted as a measure of a country's inventive output. Still, the table is sufficiently suggestive for our purposes. We see, for example, that in 1988 Ireland contributed a relatively small share of the world's domestically-held patents, meaning that almost all of its technological advances were probably imported. In contrast, Japan heads the list in terms of number of patents, though that number is grossly misleading. Under Japanese law, each component of a new product is likely to require a separate patent – for example, a new type of tennis racket will elicit separate patent applications for the frame, the strings and the product as a whole. But even if we take the Japanese number at face value, 64 per cent of the OECD patents in 1988 were issued in other countries, meaning that to keep up with the remainder of the industrial world Japan had to import much, and very likely the major part, of its new technology. Indeed, it is tautology that if every one of the 24 member countries of the Organization for Economic Co-operation and Development were to stay fully abreast of the latest techniques, the average country would have to import 23/24ths of its new technology. The conclusion is clear. Not only are we all imitators; most if not all of us depend upon imitation for the bulk of our advances.

To understand why dissemination can contribute substantially to growth, we must pause to note yet another way in which one can be mislead by the standard theory. The mainstream writings on innovation, from those of Schumpeter to more recent pieces that treat R&D as a race or a "waiting game" have us think of competition in innovation as a process in which several rivals seek to design what is a *common* new product or process, for example, all working on high definition television or a laptop computer with a colour screen. Of course, cases of such similarity in the goals of innovating rivals do occur. But the evidence indicates that there is an alternative scenario that is much more common. That is the case in which the innovations of competing firms are not only different, but complementary. Each may reduce costs but the two firms' innovations together may cut costs far more than either does by itself. Or one computer manufacturer may come up with a battery that lasts longer without recharging, while another producer may find a way to cut the weight of the machine by 25 per cent. A laptop computer that has both these new features will be more avidly desired by consumers than a machine that offers only one of them.

The fact that innovations frequently differ from firm to firm, and that they are often complementary, is highly pertinent to our current discussion. In a world where this is true the firm that innovates successfully normally will not, as a consequence, achieve even temporary dominance of the market. Rather, it will continue to face very viable competitors, each of which has retained its position by introducing new products or processes of its own.

Then, rapid dissemination of technology will surely benefit consumers, because each firm can offer products that incorporate *all* of the improvements. Or, if the inventions in question are cost-reducing process changes, each of which cuts costs by, say, 1 per cent, technology dissemination may permit a process that takes advantage of all the innovative efficiencies and reduces cost by a substantial multiple of the amount each improvement by itself makes possible.

Put another way, in a world where no firm is destroyed by it's rival's inventions, quick and easy dissemination of every such invention among many enterprises serves to *multiply* its benefits by permitting many producers, rather than only one of them, to provide to consumers the cost or product advantages that the invention makes possible. By such multiplication dissemination of technology can enhance the power of each invention manifold and it thereby can contribute correspondingly to the productive powers of the world economy

III Spread of Technology in Practice

It seems clear, then, that impediments to technology transmission can constitute a serious handicap upon growth in productivity and, consequently, upon standards of living.But, then, the market mechanism would appear to be an instrument that effectively closes down this avenue of growth if, as much of the literature appears to assume, innovative firms determinedly resist the spread of their proprietary information and if, in addition, they are as effective in pursuit of this goal as they are generally taken to be in the achievement of their other objectives. That is, we should suspect, on this line of reasoning, that the profit motive will spur innovative firms to efficiency in impeding technology transfer. And the plausible result is a glacial pace in the dissemination of technological ideas.

The facts indicate otherwise. Historically, we know that at least since the Middle Ages governments and guilds did their best to prevent the spread of technology (most immediately by prohibition of the emigration of skilled workmen). We know also that these attempts were singularly unavailing. By 1825 the British Parliament discontinued almost completely its prohibitions of technology export.

In the half century since the Second World War, the evidence indicates, technology transfer attained remarkable speed. A number of studies, notably those by Professor Mansfield and his colleagues (1981, 1985) have provided estimates of the length of time intervening between date of introduction of an innovation and general spread of the pertinent information. The studies are based on a range of industries. Estimates in other studies range no higher than some 2½ years as a representative figure, while the Mansfield estimate of the mean lag period is on the order of 1 year. Clearly, this is no slow and stately process in the world of reality.

This compelling evidence leaves us with a choice between two conclusions about the role of firms in the transfer process. Either they do in fact resist it, as much of the literature suggests. But in that case, free enterprise must be uncharacteristically ineffective in its pursuit of this goal. Alternatively, there is the possibility that many firms are not nearly as opposed to the transfer of their technology as they frequently are assumed to be. One may suspect that some of them participate willingly in the process and are even disposed to help it along. I will offer evidence that both of these possibilities are in part true.

IV Technology-Disseminating Entrepreneurs

History provides some examples of inventors who deliberately sought to profit by exporting their technology. Robert Fulton attempted to sell his submarine and his torpedo to Napoleon and the Krupps sought to induce the second Bonaparte emperor to replace his brass cannon with steel. Both sales efforts failed, at great cost to their prospective customers. Modern multinational firms constitute more systematic conduits for the export of technology to their foreign branches. In such cases the transfer is entirely voluntary.

But even when the innovating firm has no desire for its technical information to migrate there are others who are more than willing to do the job. This was particularly true of Englishmen in the eighteenth and early nineteenth centuries who spread themselves over Europe and North America, bringing the steam engine, the railroad, iron and steel making techniques and many of the spate of novel products and processes that constituted the British Industrial Revolution.

These technology exporters were true entrepreneurs in every sense of the word. Their alertness revealed and exploited new productive opportunities not consisting in the discovery of innovative technology or products but in the recognition of new markets; and not markets for the final products themselves, but, rather, markets for the inventions used by those products.

The point is that such enterprising disseminators are always made available by the market mechanism by virtue of the profits promised by opportunities for dissemination. Entrepreneurs always manage to make their appearance when such profit opportunities are recognised, and they are generally energetic and often ruthless in exploiting them. The fact that an innovating firm happens to be opposed to the spread of its proprietory technology is of little moment to the disseminating entrepreneur who believes he can get away with the transfer of other firms' innovations.

Thus, there is an element of truth to the view that technology often spreads despite the opposition of the innovators. This also happens when foreign firms engage in industrial espionage, reverse engineering and a variety of other activities intended by the foreigners to capture the forbidden knowledge for themselves. Yet such hostile technology transfer is characteristically slow and costly. Reverse engineering can require a good deal of time and money and even when espionage reveals new information early, its reports are apt to be incomplete, and the information can usually result in a marketable product only after a considerable delay. In reality, as we have seen, technological knowledge typically seems to move much too quickly for such hostile devices to constitute the mainstay of the transfer process. We are, then, driven to consider the alternative hypothesis: that the export of technology often occurs, not against the wishes of the innovators, but with their approval and connivance.

V Voluntary Technology Transfer in Practice

Once again, we do not have to rely upon surmise about the behaviour of business firms in sharing and transfer of technology. The existence of at least some forms of co-operative behaviour in this arena is well documented. The newspapers have featured in their financial sections many research joint ventures, more than once with American and Japanese firms as the partners. Such activities, with their costs and their findings shared by the participants, clearly are not designed to provide differential advantages to any of the partners *vis-a-vis* one another in terms of product design or production technique. They are meant, rather, to give a communal advantage to the participants against all competitors who are outside the undertaking. This distinction between the insiders and outsiders in a technology-sharing arrangements will play a key role in the subsequent discussion.

The other extreme from the tightly organized joint venture, whose operations are governed by detailed contractual arrangements, are the very informal exchanges that Eric von Hippel (1988) has investigated so effectively. His study centred about the steel minimills in the United States. These are electric furnace mills that have restored some US steel manufacture to world leadership in terms of productivity level. Von Hippel found that most of these firms regularly engage in exchange of technological information with the others – even with direct competitors. They readily answer the others' inquiries about their own technological developments, and even train one another's personnel in the use of new devices or new procedures, not imposing any charge for the service. Of course, this is all done with the tacit understanding that the favour will be returned whenever it is appropriate. The arrangement is, apparently, quite informal, but it is implausible that it would continue indefinitely if the exchanges were persistently one-sided. That is, for any firm, X, in such a group (I refer to it as a "technology cartel"), a continuing stream of innovations of its own becomes its ticket of admission to the technological secrets of the other members.

The research joint venture and the informal and unstructured exchange arrangement are but the two extremes, the outlying varieties in the genus technology cartel. In between, one encounters all sorts of arrangements encompassing a variety of "hi-tech" activities. Computers, scientific instruments and many others are involved. In at least one of these industries, every major firm is reliably reported to have formal contracts with every other major enterprise (and with many smaller ones as well). These contracts encompass not only current patents, but also all patents within the pertinent sub-area of the industry's activities that are expected for several years after the contract is signed. Each signatory to such a (two-firm) contract is entitled to use of the other's patents, as specified in the contract, generally without payment of any usage fee. There is, however, a balance-of-trade equalization payment, whose amount is arrived at in the contract negotiation. That is, the firm that is deemed to supply the less-valuable collection of patents makes up for the deficiency by a compensating payment to the other enterprise. In that way each firm is provided an incentive not to conceal any of its inventions, for concealment only contributes toward an unfavourable balance in its payments.

The variety of exchange arrangements is great. It is by no means difficult to add examples very different in their details, but there seems little point in doing so. For the purpose of this account is merely to demonstrate that voluntary technology dissemination by innovating firms is by no means an abnormal phenomenon. On the contrary, at least in some industries it is part of the institutionalized state of affairs and many of their firms participate routinely in whatever form of process they have adopted. Certainly the traditional vision of the firm as a determined hoarder of its own innovations has far from universal validity.

The next task for us, then is to offer an explanation indicating why firms may willingly consent to dissemination of their proprietary technological knowledge, even to rival enterprises.

VI Competitive Advantage Derived from Technology Sharing

It should be clear from the discussion of the preceding section that firms provide technological information to others as a means to gain access to the proprietary information of the others. It is the *quid pro quo* in a widespread barter process. But there is more that underlies this conclusion that may not be readily apparent.

We have already noted that in practice many firms in an industry produce innovations that are complementary rather than competitive. That is, rather than all racing to come up with the same invention, firms frequently work on product improvements that can supplement one another and, typically, yield a final product that is better or more economical than that which is made possible by either firm's innovations alone.

It is this complementary character of the bulk of the innovations of two firms that can make it mutually advantageous for the two of them to trade their proprietary information, not just once, but repeatedly, over extended periods. If there were a set of homogeneous innovation goals common to all the firms in an industry there would be nothing to trade. Expectations might then indicate that the first firm to attain the universal goal would be the undisputed winner, obtaining the patent as well as industry leadership, or even monopoly status. Such circumstances make the invention process into a race, with no significant consolation prize in prospect for the runner-up. Alternatively, the innovation process with homogeneous goals may be considered so risky that each participating firm hopes some other enterprise will assume the perils entailed in being first, with the laggard likely to reap the fruits of bankruptcy of the leader. In that case the invention process dynamic becomes what the literature describes as a "waiting game".

But both of these scenarios vanish in a world in which inventions are heterogeneous and often complementary. Here, the firms do not hope to drive each other out of business or even to acquire so great an advantage over their competitors that significant monopoly power will be theirs. Each does hope for some expansion in its market share through improvement in its products and reductions in its prices. But the cast of firms in the industry is expected to change slowly, if at all, and no abrupt market share variations are usually anticipated. Since there are few common invention goals, races are less usual than may be expected and waiting games are rather rarely played, for clearly related reasons.

Why, however, should voluntary information exchange be so common as it apparently is in such circumstances? There would seem to be a loss in differential advantage to the technology trading firm that gives up the unique features of its products and processes in exchange for the technology of other firms which those firms already are providing to the market.

The incentive for membership in a technology cartel is actually far stronger than this suggests. For it gives each of the members a powerful competitive advantage over any otherwise comparable firm that either abstains voluntarily from joining the cartel or is excluded from membership. Indeed, if the market is highly competitive or contestable that is, if entry is cheap and easy, it may be difficult for non-members to survive.

To see why this is so imagine three makers of laptop computers, similar in asset size, market share and R&D budget. Suppose that A invents a clearer screen, B a longer-lived battery and C a means to reduce weight by 30 per cent, and that each of these features is about equal to the others in its ability to attract customers. If firms B and C exchange technological information and each permits the other to use its patented information, they can both produce machines enjoying two improvements while firm A has access only to one. The differential advantage of B and C over A is clear. Moreover, that differential advantage will grow if firms D.E and F and others join the technology cartel started by B and C. The cartel members, benefiting each year from the technological advantages produced by others, as well as their own, will draw further and further ahead of firm A, whose products benefit only from its own R&D

The same will be true of process improvements that serve to cut manufacturing costs. If each firm's inventions are expected to cut real cost per computer by 2 per cent per year, then the firms in a 10 member cartel may be able to reduce their costs by as much as 20 per cent per year, while our isolated firm A can counter only with a 2 per cent reduction derived from its own research efforts.

This is, obviously, bad enough for firm A, as matters have so far been described. But the situation for A is worse still if all excess profits are precluded by actual competition or even only by the threat of competition that is brought by free entry. In that case, the holders of company securities can receive a full competitive rate of return only if the firm in which they have invested is in the forefront of the industry in terms of cost and product quality. The laggard enterprise that can only offer an essentially obsolete product at the going price or cannot match the prices of its rivals will not be able to survive very long.

In this scenario, then, the tables are turned. The firm that refuses to share its proprietary information, far from acquiring a significant advantage over its rivals, is apt to find itself consigned to a position that is dangerous if not disastrous.

I have argued, moreover, that the scenario just described, far from being bizarre or even just unusual, is close to being the common state of affairs in the innovation process. If that is so it is clear that the market mechanism provides powerful incentives for voluntary dissemination of technology by business firms. It is not by happenstance but through the structure of the competitive process that cross licensing of patents, joint R&D ventures and myriad other forms of technology sharing come frequently to our attention.

VII *Technology Sharing and the Incentive for Innovative Activity*

During the discussion of the social benefits of unconstrained technology dissemination only one reservation was expressed. This was the possibility that enhanced technology transfer will serve as a disincentive for innovative activity, thus cutting off the very source of the ideas and information to be transferred. It must be admitted that such a trade-off may well be present, and that it must be counted as an offset to the contribution to growth of an enhanced pace of transfer.

Yet the conflict may not be quite as serious as it appears on first consideration. There are at least two reasons. First, the trade-off between the benefits of transfer and innovation may not be as favourably skewed toward the latter as one may be inclined to believe. Second, there may be circumstances, notably those of a technological cartel, in which enhanced dissemination actually stimulates investment in innovation rather than discouraging it.

It is not difficult to demonstrate that the relative benefits of transfer and innovation are apt to be misunderstood. It is true, of course, that if innovation were to cease altogether there would be nothing to disseminate. However, there appears to be no danger that innovation will fall to zero in the foreseeable future. The issue, rather, is the consequence of an incremental reallocation of resources between innovation and dissemination. And here it is clear that the payoff depends on the number and magnitude of the entities that will benefit from a rise in technology transfer. If an "average innovation" saves stg £X million per user firm, then the addition of one innovation to the technology stock of a firm that does not share will save an incremental stg £X million in resources. But the release of only one of the older innovations for use by N other firms can then save stg £NX million in resources. Clearly, if dissemination is not very costly in itself, and if N, the number of sharing firms is large, the net yield from release of technology for dissemination can be considerable even if it comes at the expense of a limited cut in the pace of innovation. Obviously whether or not the change will bring a net gain on balance depends on the magnitude of any resulting decrease in innovation and the number of users of the released technological information. The point is not to attempt a categorical and general evaluation of the balance, but to suggest that one cannot assume *a priori* that a reduction in innovative activity induced by facilitation of technology transfer necessarily means that the latter will not be worthwhile.

More pertinent to our analysis is the likelihood that dissemination by a technology cartel will actually stimulate investment in innovation rather than impede it. Indeed, it can be demonstrated theoretically that the larger the number of cartel members, the greater the profit-maximizing outlay on R&D by the firm will generally be, provided only that returns to R&D are not sharply diminishing and that the innovations contributed by the members of the cartel are either complementary or only *mildly* competitive[1]. The reason is straightforward. The innovations, as we have seen, are the firm's ticket of admission to the technological information possessed by the other cartel members. More than that, an increase in its own innovation entitles each firm to more information from each of the other cartel members. Even if there is no continuous relationship linking the innovation output of firm B with the amount of information it receives from firms C,D, ..., firm B will almost certainly be compensated

[1]This is proved formally in Baumol (1991)under the assumption that the firms that constitute the cartel are similar in size and product line and consequently have identical profit-maximizing values for their outputs and innovation investments. Alternatively, a Cournot oligopoly model is used to derive similar results. It is also shown that in these circumstances the formation or expansion of a technology cartel will always enhance welfare.

by the others in some way for any rise in the amount of technological knowledge it provides to them. We have, for example, noted the arrangement that is found in the real world under which a balance of information trade equalization payment is derived through negotiation between two firms that enter into a technology-exchange contract. The more innovation that firm B brings to the bargaining table in such a negotiation the more it can expect to receive at its equalization payment. Thus, by such devices, to use the economist's jargon, the technology cartel becomes an institution that at least partially internalizes the externalities generated by innovation expenditures. It reduces the spillovers from innovation that benefit free riders without compensation to the innovator. As is well known, such internalization can be expected to stimulate innovation expenditure and bring its amount closer to the level that is optimal socially.

VII Concluding Comment

We have seen, then, that in a wide variety of circumstances the market mechanism, rather than discouraging dissemination, encourages it strongly and sometimes, perhaps, even leaves the firm no other option. This is not to deny that there are cases in which reality is closer to the Schumpeterian picture, essentially that of a patent race with resistance to dissemination. Nevertheless, the evidence on the typical innovation behaviour of the major business firms indicates that they are oriented to heterogeneous and incremental improvements in products and processes. This, as we have seen, leads to the scenario in which exchange of technological information is the more normal state of affairs.

It should, therefore, no longer be surprising that technology seems to be transmitted with such impressive rapidity in practice. And along with this we obtain a clearer grasp of the market mechanism's historically unprecedented performance as an engine of productivity growth.

None of what has been said here supports any inference that the rate of technology transfer or the level of investment in innovation will tend to approximate their optimal levels, even in a world of technology cartels. Nevertheless, it is arguably true enough that they can "constantly [revolutionize] the instruments of production .... [and create] more massive and more colossal productive forces than all preceding generations together". Optimal or no, that is surely an accomplishment that is impressive.

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