October 1998

Japanese Technology Policy*

David Flath

Department of Economics, NCSU, Raleigh, NC 27695-7506

email: david_flath@ncsu.edu

Abstract

Because Japan was a late developer among the industrial countries, it adopted science and technology policies that hastened the diffusion and dissemination of existing discoveries rather than promoting new discoveries. For example, Japan's patent system encourages the early revelation of new discoveries, promotes patent licensing on terms favorable for users, and affords patent holders only limited rights of exclusivity. By encouraging imitation, Japan's patent system erodes the incentive to develop major innovations but probably does not greatly damage the incentive for large firms to develop minor advances. This explains why most of the private research efforts of Japanese firms have been directed towards development of process innovations with immediate commercial application, not towards basic scientific advances. Public support for research in Japan also reflects some of the same biases as its patent system. In spite of these aspects of Japanese technology policy, Japan has still achieved important contributions to the world's stock of knowledge including the recent perfection and diffusion of the Toyota production management system.

*Much of this paper other than the appendix is drawn from: David Flath, Japanese Economy, Oxford University Press, forthcoming (Ch. 16).

Japanese Technology Policy

Once slandered as a nation of copycats, Japan is now widely recognized as an innovator, particularly in production management. Because Japan was a late developer among the industrial countries, it adopted science and technology policies that hastened the diffusion and dissemination of existing discoveries rather than promoting new discoveries. For example, Japan's patent system encourages the early revelation of new discoveries, promotes patent licensing on terms favorable for users, and affords patent holders only limited rights of exclusivity. In spite of it, Japanese firms, particulary the large ones, have always devoted substantial resources to research and development, relying upon secrecy and imitation lags, as well as upon patents, to protect their discoveries. Most of the private research efforts of Japanese firms have been directed towards development of process innovations with immediate commercial application, not towards basic scientific advances. Public support for research in Japan also reflects some of the same biases as its patent system. In Japan, a lot of the publicly funded research is actually conducted by the private sector, as opposed to being conducted by public universities or government research institutes as is more typical of the U.S. and some other countries. Also, less of the government-supported research is directly related to national defense in Japan, than is true of the U.S..

RESOURCES DEVOTED TO INVENTION AND DISCOVERY

The advanced countries including Japan all devote substantial resources to research and development. Furthermore, research efforts are heavily focused on the same few industries. The Table 1 details spending on research and development in Japan in fiscal year 1995, both in aggregate and in selected broadly defined industries. In Japan the chemicals, electric machinery, and transportation equipment industries have absorbed more than two thirds of all public and private resources devoted to invention and discovery. These same "high technology" industries have been the focus of research and development efforts in the U.S. and other countries also. The total funds devoted to research in Japan amounted to approximately 3% of fiscal year 1991 GNP, of which 78 percent were the result of private contributions, and 22 percent government contributions. Spending by corporations accounted for 71 percent of all spending.

In these data, spending by corporations is categorized by purpose according to the following criteria. "Applied" research is devoted to the general pursuit of commercial applications, whereas "developmental" spending is that which leads directly to commercial products. "Basic" research is any that is precommercial.

Table 1. Research and development spending in Japan, 1995.

	expenditures on research, fiscal yr 1991 (billions of yen)	% composition basic	applied	developmental
spending by private corporations in selected industries:				
chemicals	1,555	14.3	26.1	59.6
electric machinery	3,274	4.1	20.1	75.8
transportation equipment	1,361	4.2	13.4	82.4
all other industries	3,206	6.5	25.8	67.7
total	9,396	6.6	22.0	71.3
spending by research institutes	1,920			
spending by universities	1,875			
total spending	13,191			
sources of funds				
government	2,866	(21.7% of total)		
private	10,310	(78.2% of total)		
foreign	15	(0.1% of total)		

Source: Science and technology agency, Kagaku gijutusu yÇran (Indicators of science and technology), (1997),Table 1-4 (pp.34-5), and Table 2-2 (pp. 58-9).

The Table 2 compares the research spending in Japan with that of other nations. Japan's overall spending in relation to its GNP is commensurate with that of other developed nations. But a larger percentage of research spending in Japan is privately financed rather than government financed, and a significantly smaller percentage of that which is government financed is dedicated to national defense.

The rationale for government spending on research is quite transparent. Knowledge is the classic example of a public good. Its value to the nation often exceeds whatever revenues an inventor himself might hope to capture even under a patent system as exclusionary as that of the United States. The pursuit of knowledge, like the erection of bridges, lighthouses, and national defenses, may be privately unprofitable yet socially beneficial. For this reason governments that themselves provide research and development can hope to raise the national income. There have been many attempts to evaluate the actual contribution of both private and public research expenditures to national income, in both Japan and the United States. Our next task is to examine these estimates.

Table 2. International comparison of R&D spending, 1985 and 1995.

	expenditures on research and development, (% of GDP)[a]		% composition by source					
			government					
			nondefense		defense		private	
	1985	1995	1985	1995	1985	1995	1985	1995
JAPAN	2.71	2.95	20.4	22.0	0.6	0.9	79.0	77.1
United States	2.72	2.46	20.6	17.3	29.7	19.8	49.7	62.9
Germany	2.75	2.28	33.1	35.0	4.5	0.5	62.4	64.5
France	2.23	2.34	34.4	33.4	18.5	11.2	47.1	55.4
United Kingdom	2.25	2.05	21.5	21.0	20.7	12.3	57.8	66.7
Italy	1.1		40.6		5.1		48.3	
Canada	1.4		46.0		2.9		51.1	
OECD	2.3		24.9		18.1		57.0	

[a] For Italy, Canada and OECD: percent of GNP.

Sources: For Italy, Canada and OECD: OECD, OECD Science and Technology Indicators Report no. 3: R&D, Production, and Diffusion of Technology, Paris, 1989. All others: Science and technology agency, Kagaku gijutusu yÇran (Indicators of science and technology), (1997), Figure 2 (p. 4) and Figure 4 (p. 6).

Measuring the Returns to Research and Development

In economics, technological advance means a shift in the production function. The production function indicates the maximum value of output derivable from given inputs if the most effective known method is used. For instance the Cobb-Douglas production function

$$Q=aK^{b}L^{1-b}, \text{ where } a>0, \text{ and } 1>b>0$$

indicates the maximum output Q that can be produced with K units of capital and L of labor. An increase in the parameter "a" is an unambiguous advance in technology ("neutral" technological change). A shift in the production function that entailed changes in "b" would be an advance for some combinations (K,L) but not all. Such a change in technology is referred to as "biased" (in favor of capital, or capital-saving (capital-augmenting), and labor-using, if db/dt >0; and in favor of labor, or labor-saving and capital-using, if db/dt<0).

Economists measure technological advance by estimating the production function of firms in an industry. Changes in output not attributable to changes in capital or labor are adduced to be shifts in the production function. Following this logic, a precise measure of the rate of technological advance under the Cobb-Douglas production function is:

$$1/Q\ dQ/dt - b\ 1/K\ dK/dt - (1-b)\ 1/L\ dL/dt\ ,$$

which is called the rate of change in total factor productivity.[1] If technical change is neutral (db/dt=0) then the rate of change in total factor productivity equals the rate of change in parameter "a" of the production function: 1/a da/dt.

Industries that invest more heavily in research and development have the fastest rates of technical change. The economist Mansfield (and others including Minasian, Terleckyj, and Griliches) have discovered a statistical relation between the rate of change in total factor productivity and research and development spending as follows. Define the accumulated stock of knowledge R as an input analogous to capital or labor so that the production function becomes

$$Q=\alpha R^{\theta}K^{b}L^{1-b}, \text{ or equivalently } \alpha R^{\theta}=a.$$

Now if technical change is not biased towards capital or labor (db/dt = 0), then the rate of change in total factor productivity becomes equal to

$$1/\alpha\ d\alpha/dt\ +\ (\theta Q/R)\ 1/Q\ dR/dt.$$

Of course the "stock of knowledge" R is itself not directly measurable. However an industry or firm's incremental advance in knowledge dR/dt relative to its output Q can be equated to its annual *spending* on research and development relative to the *market value* of its final output (that is its value added). The parameter $\theta Q/R$ is estimated by regressing estimates of rate of change in total factor productivity on annual expenditures on research and development relative to value added. Because θ is defined as the elasticity of output with respect to accumulated knowledge ($\theta \equiv (\partial Q/\partial R)R/Q$) it

[1] A "factor" is a productive input such as labor or capital. Labor productivity is output per unit of labor. Total factor productivity is a geometric weighted average of the productivities of all factors of production.

follows that $\theta Q/R = \partial Q/\partial R$ represents the perpetual addition to annual output associated with an added increment of knowledge, the result of expending one unit of current output on research and development. We can refer to estimates of $\theta Q/R$ as the rate-of-return from research and development spending.

A number of scholars have estimated the rate-of-return from research and development spending for firms and industries in the U.S., and in Japan, using Mansfield's method as just outlined. First, the rate of change in total factor productivity is constructed as a residual rate of change in value of final output unexplained by a regression of output on capital and labor inputs. Then, the rate of change in total factor productivity is regressed on research and development spending relative to value of final output. The slope coefficient from this regression is an estimate of the rate-of-return from research and development spending. The Table 3 reports such estimates for American and Japanese firms and industries.

Table 3. Estimates of the rate-of-return from R&D in Japan and America.

study	sample period	rate-of-return (percent)	object of analysis
JAPAN			
Odagiri (1985)	1960-66	30	15 manufacturing industries
	1966-73	60	" "
	1973-77	30	" "
Yaginuma et al (1982)	1973-79	54	10 manufacturing industries
Suzuki & Miyagiwa (1986)	1974-79	52	50 manufacturing industries
Miyagawa (1983)	1971-81	81	12 manufacturing industries
Goto et al (1986)	1976-80	22-51	50 manufacturing industries
Mansfield (1988)	1960-79	33-42	17 manufacturing industries
Goto and Wakasugi (1988)	1976-79	39	17 manufacturing industries
Goto and Suzuki (1989)	1976-84	40	7 manufacturing industries
....			
Odagiri and Iwata (1986)	1966-73	20	135 companies
	1974-82	17	168 companies
UNITED STATES			
Minasian (1969)	1948-57	54	chemical industry
Griliches (1973)	1958-63	40	85 manufacturing industries
Terleckyj (1974)	1948-66	37	20 manufacturing industries
Nadiri (1980)	1958-75	22	11 manufacturing industries
Grilliches and Lichtenberg (1984)	1964-73	11	193 manufacturing industries
	1968-78	31	" "
....			
Griliches (1980)	1957-65	17	883 large companies
Mansfield (1980)	1960-76	27	10 petroleum firms and 6 chemical firms
Link (1982)	1975-79	31	97 firms in the petroleum, chemicals and machinery industries

Sources: JAPAN: H. Odagiri (1985) "Research Activity, Output Growth, and Productivity Increase in Japanese Manufacturing Industries", Research Policy, vol. 14, no. 3, pp. 117-130; H. Yaginuma, K. Horiuchi, M. Nakanishi, and T. Miyagiwa (1982) Setsubi toshi kenkyã '81 (Business investment survey '81) keizai keiei kenkyã, 3-4, Japan Development Bank; K. Suzuki and T. Miyagiwa (1986) Nihon no kigyo toshi to kenkyã kaihatsu senryaku (Research and development strategy and Japanese industrial investment) Toyo keizai shinposha; T. Miyagawa (1983) Kenkyã kaihatsu shishutsu no keizai koka to seifu no yakuwari (The government's role in the economic effects of R&D expenditures), Kikan gendai keizai, vol. 55, pp. 139-150; A. Goto, N. Honjo, K. Suzuki, and M. Takinosawa (1986) Kenkyã kaihatsu to gijutsu shinpo no keizai bunseki (Economic analysis of technical progress and research and development), Keizai bunseki, no. 103 (Keizai kikakucho); E. Mansfield (1988) "Industrial R&D in Japan and the United States: A Comparative Study", American Economic Review, vol. 78, no. 2, pp. 223-228; A. Goto and R. Wakasugi (1988) "Technology Policy", Ch. 7 in R. Komiya, M. Okuno and K. Suzumura Industrial Policy of Japan, Academic Press, Inc., pp. 183-204; A. Goto and K. Suzuki (1989) "R&D Capital, Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries", The Review of Economics and Statistics, vol. 71, no. 4, pp. 555-64; H. Odagiri and H. Iwata (1986) "The Impact of R&D on Productivity Increase in Japanese Manufacturing Industries", Research Policy, 15, pp. 13-19.

UNITED STATES: J. Minasian (1969) "Research and Development, Production Functions and Rates of Returns", American Economic Review, vol. 59, pp. 80-85; Z. Griliches (1973) "Research Expenditures and Growth Accounting", in B. R. Williams, ed., Science and Technology in Economic Growth, New York: John Wiley and Sons, pp. 59-83; N. E. Terleckyj (1974) "Effects of R&D on the Productivity Growth of Industries: An Exploratory Study", Washington D.C.: National Planning Association; M. I. Nadiri (1980) "Contributions and Developments of Research and Development Expenditures in the U.S. Manufacturing Industries", in G.M. Furstenberg, ed., Capital, Efficiency and Growth, Ballinger, pp. 362-392; Z. Griliches and F. Lichtenberg (1984) "interindustry Technology Flows and Productivity Growth; A Reexamination", The Review of Economics and Statistics, May, pp. 324-329; Z. Griliches (1980) "Returns to Research and Development Expenditures in the Private Sector", in J. W. Kendrick and B.N. Vaccara, eds., New Developments in Productivity Measurement and Analysis, University of Chicago Press, pp. ?; Mansfield (1980) "Basic Research and Productivity Increase in Manufacturing", American Economic Review, vol. 70, pp. 863-73; A. Link (1982) "Productivity Growth, Environmental Regulations, and the Composition of R&D", Bell Journal of Economics, vol. 13, no.2, pp. 548-54.

The estimates in Table 3 reveal two things. First, individual firms' rates-of-return from their own respective R&D spending are rather less than broadly defined industries' rates-of-return from their respective R&D spending. An explanation for this resides in the fact that research and development by one firm often leads to advances that other firms then imitate without themselves incurring costs of discovery. These intra-industry spillovers contribute to the industry's rate-of-return from R&D spending but not to individual firms'.

Second, the industry-wide rate-of-return from R&D spending is consistently estimated to be higher in Japan than in the U.S. when overlapping periods are studied. This suggests that imitation or licensed use of new discoveries is more prevalent in Japan than in the U.S.. To understand the reasons we need to explore aspects of the patent system of Japan.

PATENT SYSTEM OF JAPAN

Invention and innovation clearly benefit society. But once a new technology is introduced, others can observe and imitate it without themselves incurring the costs of initial discovery. As imitative rivals learn how to produce at lower costs, they expand output, depressing product price and eroding whatever rewards might have been captured by the original innovator. As Andrew Carnegie once said: "Pioneer'n don't pay." If this were the whole story it would be puzzling indeed that many companies devote substantial resources to research and development. But of course it is not the whole story. To spur innovation, most countries, including Japan, award patents to inventors. A patent is an exclusive government franchise for the use or sale of rights to a new product or new method of producing, in effect a monopoly. One of the reasons that private companies hope to capture some rewards from their own new discoveries is the prospect of receiving a patent.

Japan's first patent law was enacted at the beginning of the twentieth century and its last significant amendment was in 1959. The U.S. Constitution empowers Congress to authorize patents "to promote the progress of Science and the useful Arts" and America's first patent laws were enacted in 1790, 1793 and 1836. The last of these established the U.S. Patent Office and encoded the basic principles upon which current American patent laws still rest. British patent laws originated in the seventeenth century.

Under the laws of both Japan and the U.S. an invention must meet standards of novelty, utility, and nonobviousness if it is to be patentable. But the novelty requirement is rather diluted in Japan compared to other countries.[2] A minor modification of an already patented invention is far more likely to be considered new and, to that extent, itself worthy of patent protection in Japan. To obtain significant rights of exclusivity under the patent system of Japan therefore requires multiple patents, "boxing in" the new invention. Particularly so because until 1988 each patent application could make at most one claim. And in fact the number of patents applied for and issued in Japan has been quite large in comparison to the numbers applied for and issued in other countries.[3]

---

[2]For some of the details of Japan’s patent laws that bear on the novelty requirement, consult the following: Arthur Wineberg, "The Japanese Patent System: A Non-Tariff Barrier to Foreign Businesses?," Journal of World Trade Law, vol. 22, no. 1, 1988, pp. 11-22.

[3]Because the Japanese patent system induces applicants to follow the "boxing in" strategy, the number of patents issued in Japan, unadjusted for the breadth of the rights they confer, surely gives an inflated measure of Japan's inventiveness relative to that of other nations. Earl H. Kinmouth, "Japanese Patents: Olympic Gold or Public Relations Brass?", Pacific Affairs, vol. 60, no. 2, Summer 1987, pp. 173-199.

The patent system of Japan promotes the early revelation of new discoveries. In Japan, as in the European countries but unlike America, the first to file for a patent gains priority. In America the first to invent holds priority. That is, in the U.S. only the inventor may apply for a patent in the first year after announcing his invention. Granting priority to the first to file as in Japan encourages inventors to apply for patents quickly to preempt other claims. And in Japan patent applications are not secret as in the U.S.. Japan's patent office publishes all the applications eighteen months after it receives them. Upon a request for examination of the application (either by the applicant, an opponent, or other) the patent application is published a second time. Those who would challenge the originality or obviousness of the patent claim may then state their cases to the authorities. The applicant has three months to respond to each pre-grant challenge. Once a patent has been issued, challenges are both more costly and less likely to succeed. The U.S. patent office publishes patent applications only after it issues a patent, and patents can only be opposed after they are issued.

Japan's system of allowing opposition to patents before they are even issued promotes the licensing out of new inventions on terms favorable to users. If not offered favorable licensing terms, competitors can threaten to oppose an application, greatly prolonging and complicating the process of receiving a patent. The pre-grant opposition places a burden on the patent examiners in Japan to which their numbers and resources are not commensurate--a calculated policy of the government. The time from application to grant in Japan can be as long as ten years. And in Japan, patent rights expire 20 years from the date of application or 15 years from the date of grant whichever is shorter. (In the U.S., patent rights extend 17 years from the date of grant). In Japan, pre-grant commercial uses of an eventually patented invention are not considered infringements but do entitle the patent holder to retroactive licensing fees. This amounts to a form of compulsory licensing of new inventions. In the U.S., patents are granted more quickly and competitors therefore have less opportunity to employ a pending patent. Also in the U.S., competitors are unable to threaten pre-grant opposition as a bargaining lever in obtaining favorable terms for licensed use of pending patents.

In summary, Japan's patent system promotes the issuance of patents that are narrower in breadth than the patents issued in the U.S., encourages the early revelation of new discoveries, and encourages the licensing of inventions on terms favorable to users. The patent system of Japan, by promoting licensing and imitation of inventions, contributes to the larger industry-wide rate-of-return on resources devoted to R&D in Japan than elsewhere.

Effects of Licensing and Imitation on the Allocation of Resources to Invention

Though the patent system of Japan affords smaller rewards for inventors than does that of the U.S., it is nevertheless one spur to Japanese companies' investments in research and development documented earlier. But there are also other inducements. A discovery may prove profitable even if it does not result in the issuance of a patent. For one thing, imitation itself is neither costless nor can it be instantaneous. There is little doubt that much of the R&D spending by corporations in Japan (and elsewhere!) is directed at understanding and adapting new products and technologies developed by others.

Licensed uses avoid the costs of imitation but entail payment of fees to the inventor. Licensing therefore preserves some incentives for invention while simultaneously promoting diffusion. Compulsory licensing on terms favorable to users is an even greater spur to the diffusion of new inventions.

Because Japan's patent system encourages licensing on terms favorable to users and allows ample opportunity for imitation, it shifts many of the advantages of innovation away from the inventor and towards other firms in the same industry as an inventor. For this reason, research and development in Japan can take the form of a waiting game rather than a race, each firm standing back and hoping for the others to develop an innovation rather than rushing to be the first to develop it. But this is more likely to be true of major innovations that drastically transform production methods and greatly reduce costs than it is of minor innovations that allow only incremental reductions in marginal costs. Katz and Shapiro have demonstrated an algebraic example of innovation in a duopoly, a simple model that artfully incorporates the relevant issues.[4] The example is fully explicated in an appendix, but its logic may be transparent enough even without reference to the finer details.

In the Katz and Shapiro example, a large firm gains more than a small rival from being the first to introduce a minor innovation whether or not licensing or imitation is present. The greater output over which a large firm realizes a cost reduction is decisive for minor innovations. The minor innovation game is a race and the large firms win. But the major innovation game can take the form of a waiting game rather than a race. If imitation is relatively easy (or equivalently, compulsory licensing on terms favorable to users is present), large firms will wait for smaller firms or outsiders to introduce major innovations. With imitation, major innovations sweep through an industry and erode the profits of the large firms by displacing the technologies in which they have established superiority. Nor can small firms expect to reap a bonanza by introducing major innovations because, although only they will have incurred the development costs, the technology will be available to all.

By encouraging imitation, Japan's patent system erodes the incentive to develop major innovations but probably does not greatly damage the incentive to develop minor advances, and at the same time promotes the rapid, efficient, and widespread adoption of new technologies of either kind once they are introduced. In this way, the patent system of Japan makes the greatest advantage of Japan's historical position as a late developer, a borrower and adapter of foreign technology rather

[4]Michael L. Katz and Carl Shapiro. "R&D Rivalry with Licensing or Imitation", The American Economic Review, vol. 77, no. 3, June 1987, pp. 402-420.

than a technology leader.[5] Nevertheless, Japan's contributions to the world stock of knowledge should not be slighted. We next examine a supporting example.

JAPAN AS A TECHNOLOGICAL INNOVATOR

There are many possible avenues of invention and discovery. Inventors will tend to choose only the avenues they expect will confer the greatest economic rewards. Japan historically has experienced relative scarcity of land and natural resources. Technological advances that economize on space and energy, and exploit other inputs more fully, have therefore long had a larger payoff in Japan than in other countries. And this is reflected in the actual path of technical change in Japan. The important innovations originating in Japan in this century have been labor-using but land-and-energy-saving, in other words, not neutral but biased in favor of the inputs having lower relative prices in Japan than in other countries. In agriculture, Japan was the first in the world to develop hybrid varieties of crops complementary to the heavy use of fertilizer and also the first to develop chemical fertilizers.[6] In manufacturing, the production management system developed at Toyota since the 1950's has, among other improvements, enabled drastic reductions in the use of space on assembly lines, and thus economizing on resources more scarce in Japan than elsewhere. Though first developed in Japan, the Toyota production system is now transforming manufacturing enterprises throughout the world. This merits a little bit closer treatment. In particular, the arrangements between Toyota and its subcontractors are now widely recognized as a path-breaking technological advance.

The Toyota System of Production Management

Japanese firms, beginning with Toyota, have developed novel, innovative, and efficient new ways of implementing and enforcing agreements with subcontractors. Subcontractors are firms that supply parts to other firms according to order. There are close complementarities between Toyota's innovations in production management and its growing reliance on a complex hierarchy of subcontractors. The Toyota production management system entails the use of kanban or "signboards" attached to work in progress on the assembly line. When a subassembly is completed its signboard is detached and returned to the previous workstation. Signboards released from the next workstation are attached to newly started subassemblies. A dearth of such signboards (released from the next station) indicates a bottleneck at the next station and is a signal for workers to move

[5] So argues: Janusz A. Ordover, "A Patent System for Both Diffusion and Exclusion," The Journal of Economic Perspectives, vol. 5, no. 1, Winter 1991, pp. 43-60.

[6] Hayami and Ruttan argue that the land-and-energy-saving bias of technological advance in Japanese agricultural reflects calculated attempts to economize on the productive resources that have been relatively most scarce in Japan: Yujiro Hayami and V. W. Ruttan. "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960", The Journal of Political Economy, vol. 78, no. 5, Sept./Oct. 1970, pp. 1115-1141.

from other stations to that one. A plethora of signboards released from the next station is a sign that a bottleneck is forming at one's own station and a signal to hasten efforts. Toyota uses this system not only on the assembly line but also with subcontractors. That is subcontractors time their deliveries of parts according to the number of signboards released by the first station on the assembly line. Efficient implementation of the kanban system of inventory control requires frequent and timely delivery of parts produced to fine tolerances and with a minimum of defects. This has required the development of a finely tuned system of subcontracting agreements in which Toyota's expectations are communicated in detail to subcontractors and made to be in the self-interest of the subcontractors to fulfill. Other firms have imitated Toyota's successful innovations.

Subcontracting

Though arrangements between manufacturing firms in Japan and their subcontractors are seldom prescribed in writing, it would be wrong to infer from this that the arrangements are ambiguous, loose, or subject to the whims of one party or the other. On the contrary, these contractual stipulations require the agreement of both parties, are quite precise, and are seldom abrogated. The subcontracting agreements in the automobile industry typically specify the prices to be paid for parts over the subsequent four years as a linear transformation of the buyer's own later estimates of components of the subcontractor's unit cost (including energy, materials, and labor).[7]

The specific parameters of these pricing rules reflect a subtle calculation. If the price is made to be simply proportionate to unit costs, then the subcontractor will have no incentive to seek cost reductions. Yet, if the price is completely divorced from costs then the subcontractor will bear all the risk associated with factors that shift costs and are beyond his control, even though the customer is likely to be a large firm better equipped to bear such risks than the subcontractor which may well be a small family enterprise.

Contracts between Japanese firms and their subcontractors do indeed reflect these considerations. Kawasaki and McMillan[8] have demonstrated that subcontractors that are small (measured by number of employees) and therefore likely to be highly averse to risk, experience less variation in profits than do the larger subcontractors. This indicates that price stipulations are gauged to more fully reward subcontractors for their cost reducing efforts the less is their aversion to the risk that such rewards inevitably entail. Kawasaki and McMillan also find that price is more sensitive to changes in unit cost for subcontractors that are not only smaller or more risk averse but also for those who experience less predictable cost changes or who secure a smaller portion of inputs themselves and therefore have less discretion in determining their unit costs. This is a further indication that where incentives for cost reduction are either more costly or less valuable, they are less likely to be

---

[7]Asanuma Banri "The Organization of Parts Purchases in the Japanese Automotive Industry," and "The Contractual Practice for Parts Supply in the Japanese Automotive Industry," Japanese Economic Studies, Summer 1985, pp. 32-78.

[8]Seiichi Kawasaki and John McMillan, "The Design of Contracts: Evidence from Japanese Subcontracting," Journal of the Japanese and International Economies, vol. 1, 1987, pp. 327-349.

present.

Managers dictate the organization of production within the firm. When firms instead contract out for parts and services, organization is not imposed by anyone but nevertheless emerges out of self-interest directed behavior in response to market incentives. Subcontracting is most viable where command and control is cumbersome and ineffective and where the costs of assuring compliance with the terms of agreements is least. Not all Japanese auto manufacturers rely on subcontractors to the same extent. Toyota has the most subcontractors and Honda the least. Automobiles have thousands of small parts many of which can be identified as defective without observing the process by which they were produced. Command and control of every detail of manufacture is therefore cumbersome and in many cases inessential. Nevertheless, subcontracting is sometimes still not viable because opportunism cannot be easily forestalled.

Opportunism can mean failing to make investments that reduce the costs of serving a customer, after having received a payment from the customer in anticipation of the investment. Opportunism can also mean substituting products or services of inferior quality after having received a payment from a customer in anticipation of superior products or services. Of course, prudent customers will anticipate opportunism and take steps to forestall it. But where countermeasures are either ineffective or prohibitively costly, production of the parts within the firm itself may be the only viable alternative. For instance, the supplier who contemplates behaving opportunistically can expect an immediate benefit but losses in the future. The immediate benefit arises from avoiding costs. The future losses arise from the reduced demands of customers who, having failed to anticipate opportunism once, are unlikely to do so again. Generally, opportunism is less likely to be in the narrow self-interest of suppliers where (1) frequency of transactions is great--so that the scope for immediate benefits from avoiding costs is smaller, (2) duration of trade is long--so that future losses attending a reputation for behaving opportunistically are likely to be great, and (3) interest rates are low--so that future losses have a greater present value.

The main Toyota assembly plants in Aichi prefecture are in close geographic proximity to the subcontractors. In contrast, the suppliers of parts to Honda are geographically scattered. For this reason, suppliers deliver parts more frequently and in smaller loads to Toyota than to Honda. Also Toyota has been an innovator in developing arrangements with subcontractors but Honda is an imitator or latecomer. Toyota therefore has a stronger reputation than Honda for maintaining lasting relations with subcontractors. Both are factors that account for the more extensive reliance on subcontracting by Toyota than Honda.

CONCLUSION

Many aspects of technological innovation in Japan reflect local considerations. As a late developer, Japan derived great benefit from borrowing and adapting foreign technology. This process has been abetted by a patent system that promotes the early revelation of new discoveries, encourages licensing and imitation and affords weak ownership rights in inventions. Not surprisingly, given these aspects of the Japanese patent system, most private inventive activity in Japan is directed at incremental advances and conducted by large firms who stand to profit the most from small reductions in unit costs. The government of Japan also devotes significant resources to research, but mostly applied research rather than basic scientific discovery, and very little of it is directed at the development of weapons systems.

The myth that Japan is a nation incapable of original innovation is soundly refuted by counterexamples, including the development of hybrid varieties of crops early in this century, decades before the United States, and by the recent perfection and diffusion of the Toyota production management system, that includes very sophisticated and finely calibrated arrangements with subcontractors.

Appendix: The Katz and Shapiro model[9] and the Japanese patent system.

Katz and Shapiro have artfully crafted a very rich model of R&D rivalry that is an indispensable framework for examining the myriad economic implications of a patent system like that of Japan. This appendix sets out the essential details of the model and draws out the main points for evaluating Japanese technology policy.

In the model, ongoing basic research is continually lowering the costs of development. Suppose that the present value, as viewed from time=0, of the cost of development at time T equals $K(T)=K_0e^{-\lambda T}$, where λ is greater than the (continuously compounded) interest rate r. Notice that the cost of developing is continually decreasing but at a diminishing rate: $dK/dT=-\lambda K(T)<0$ and $d^2K/dt^2=\lambda^2K(T)>0$.

There are two firms in the industry, and both have constant unit costs of production. The industry leader, firm 1, initially has lower unit costs than the other, firm 2: $c_1^0<c_2^0$. If firm 1 develops, its unit costs become reduced to $c_1^1=c_1^0-\delta$, and if firm 2 develops, its unit costs become $c_2^2=c_2^0-\delta-\varepsilon$. Assume that $-\delta < \varepsilon < c_2^0-c_1^0$. In other words, if firm 2 develops it does reduce its own unit costs, but if both firms develop then the leader will still have lower costs than the other.

The present value of each firm depends upon whether it, or the other, is the one to develop, and depends upon the time at which development occurs. Denote the present value of firm i, again as viewed at time 0, if it is the first to develop and does so at time T by $W_i(T)$. And denote its present value if the other firm, $j\neq i$, is the first to develop at T by $L_i(T)$. Now

$$W_i(T)= \int_0^T \pi_i^0e^{-rt}\, dt \quad + \int_0^\infty \pi_i^ie^{-rt}\, dt \;-\; K(T)$$

$$= ((1-e^{-rT})\pi_i^0 + e^{-rT}\pi_i^i) / r \quad - \quad K(T)\ .$$

Note use of the fact that $d(-e^{-rt}/r)/dr = e^{-rt}$. By similar reasoning,

$$L_i(T) = ((1-e^{-rT})\pi_i^0 + e^{-rT}\pi_i^j) / r\ .$$

Notice that only the firm that develops incurs development costs K.

The firm's ***stand-alone development date*** is the date at which it would develop if it believed that the other never would develop. It is the date $\hat{\tau}_i$ at which $W_i(T)$ attains a maximum value. The firm's ***earliest date of preemption*** is the date $\tilde{\tau}_i$ at which $W_i(T)=L_i(T)$. From the previous expressions we have that

$$\pi_i^i - \pi_i^0 = -K'(\hat{\tau}_i)\, e^{r\hat{T}_i}$$

or

$$\hat{\tau}_i = (\lambda-r)^{-1} \ln(\lambda K_0/(\pi_i^i -\pi_i^0))\ .$$

[9]Michael L. Katz and Carl Shapiro. "R&D Rivalry with Licensing or Imitation", The American Economic Review, vol. 77, no. 3, June 1987, pp. 402-420.

In other words, the firm that experiences the larger increase in flow profit if it is the one to develop ($\pi_i^i - \pi_i^0$), has the earlier stand-alone development date $\hat{T}_i$.

By similar reasoning, firm i's earliest date of preemption fulfills the following

$$\pi_i^i - \pi_i^j = rK(\tilde{T}_i)\, e^{r\tilde{T}_i}$$

or

$$\tilde{T}_i = (\lambda\text{-}r)^{-1} \ln(rK_0/(\pi_i^i - \pi_i^j))$$

In other words, the firm that gains a larger increase in profit flow if it rather than the other develops ($\pi_i^i - \pi_i^j$), has the earlier, earliest date of preemption $\tilde{T}_i$.

Katz and Shapiro imagine that the industry is a Cournot duopoly. The flow profits under each eventuality thus have natural interpretations. Where there is no licensing or imitation, so that at most one of the firms develops, unless the innovation would reduce the follower's costs by a far greater percentage than it would the leader's, the leader has both the greater stand-alone development incentive:

$$(\pi_1^1 - \pi_1^0) > (\pi_2^2 - \pi_2^0)$$

and greater preemption incentive:

$(\pi_1^1 - \pi_1^2) > (\pi_2^2 - \pi_2^1)$...which is equivalent to the statement that the industry profit is greater when firm 1 develops than when firm 2 does: $(\pi_1^1 + \pi_2^1) > (\pi_1^2 + \pi_2^2)$.

To put it another way, with no licensing or imitation possible, the usual presumption is that the leader (firm 1) has the earlier stand-alone development date ($\hat{T}_1 < \hat{T}_2$), and earlier, earliest date of preemption ($\tilde{T}_1 < \tilde{T}_2$). In this case, the leader is the first to develop, and does so at the earlier of its own stand-alone development date or follower's earliest date of preemption, earlier of $\hat{T}_1$ and $\tilde{T}_2$. The leader preempts the follower only if necessary to assure that it wins the development race. Under a regime of weak patent protection, and wide opportunities for imitation, matters are a little different.

Perfect imitation means that whichever firm develops, both firms immediately obtain the cost-reducing innovation: $c_j^i = c_j^j$. Imitation has lower costs than development. For example, Katz and Shapiro suppose that the costs of imitation equal $\gamma K(T)$, where $0<\gamma<1$. (Mansfield estimated a parameter similar to γ, using data on development expenditures and measures of technical advance in selected US manufacturing industries and found it to be $\gamma \approx 0.6$). As long as imitation is less costly than development, both firms will prefer that the other develop; neither has any incentive to preempt the other ($\tilde{T}_1 = \tilde{T}_2 = \infty$). So with perfect imitation, development is a waiting game rather than a race. The firm i with the greater stand-alone development incentive ($\pi_i^i - \pi_i^0$) develops first, and does so at its own stand-alone development date $\hat{T}_i$.

In the Cournot duopoly, with perfect imitation, the leader has a greater stand-alone development incentive for minor innovations (for which $\varepsilon<<$ and $\delta<<$), but the follower has a greater stand-alone development incentive for major ones (for which $\varepsilon>>$ and $\delta>>$). Here, a major innovation is one that, if adopted by both firms, greatly increases the market share of the firm that initially is the follower, while a minor innovation is one that, if adopted by both firms, has little effect on market shares. For minor innovations adopted by one firm and imitated by the other, the larger output over which the leader exploits cost reductions is decisive in conferring greater stand-alone development incentives on it than on the follower. But for major innovations, the erosion of market share of the leader, when either firm develops and the other imitates, confers greater stand-alone development incentives on the follower.

Development will usually occur later under a regime in which imitation is possible compared to one in which it is not. This is because, under the regime of imitation, both firms have weaker stand-alone development incentives, and weaker (in fact, nonexistent) preemption incentives. The retarding effect of this on the timing of development is larger for major innovations than for minor ones. (The contrary instances in which imitation hastens rather than retards development depend upon asymmetries in which the follower obtains significantly greater cost reduction from innovation than does the leader).

The figures illustrate possible outcomes. Figure A1 depicts a development "race" as might be characteristic of regimes with strong patent protection as in the U.S., while Figure A2 depicts a "waiting game" as might occur for major innovations under regimes with weak patent rights and wide opportunities for imitation as in Japan.

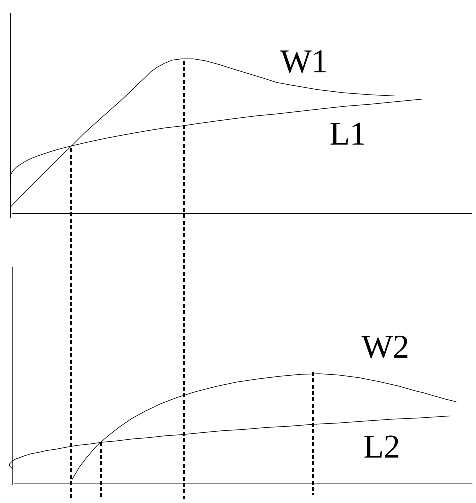

Figure A1. The leader, firm 1, preempts (at the follower's earliest date of preemption) to prevent the follower from doing so. This configuration might be characteristic of a regime like that of the U.S. with strong patent protection and few opportunities for imitation.

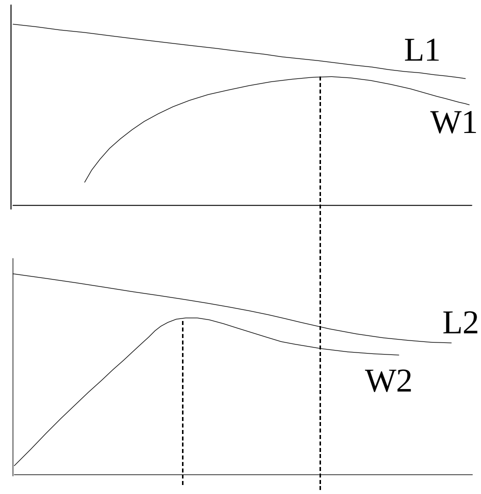

Figure A2. The follower, firm 2, develops at its own stand-alone date rather than wait for the leader. This configuration might be characteristic of major innovations under a regime like Japan's with weak patent protection and wide opportunities for imitation. Under this same regime, minor innovations are apt to elicit a race, which the leader wins, as in Figure A1.

Works Cited

Asanuma Banri "The Organization of Parts Purchases in the Japanese Automotive Industry," and "The Contractual Practice for Parts Supply in the Japanese Automotive Industry," Japanese Economic Studies, Summer 1985, pp. 32-78.

Goto, A., N. Honjo, K. Suzuki, and M. Takinosawa. Kenkyū kaihatsu to gijutsu shinpo no keizai bunseki (Economic analysis of technical progress and research and development), Keizai bunseki, no. 103 (Keizai kikakucho), 1986.

Goto, A. and K. Suzuki "R&D Capital, Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries", The Review of Economics and Statistics, vol. 71, no. 4, 1989, pp. 555-64.

Goto, A. and R. Wakasugi. "Technology Policy", Ch. 7 in R. Komiya, M. Okuno and K. Suzumura Industrial Policy of Japan, Academic Press, Inc., 1988, pp. 183-204.

Griliches, Z. "Research Expenditures and Growth Accounting", in B. R. Williams, ed., Science and Technology in Economic Growth, New York: John Wiley and Sons, 1973, pp. 59-83.

Griliches, Z. "Returns to Research and Development Expenditures in the Private Sector", in J. W. Kendrick and B.N. Vaccara, eds., New Developments in Productivity Measurement and Analysis, University of Chicago Press, 1980, pp. ?.

Griliches, Z. and F. Lichtenberg. "Interindustry Technology Flows and Productivity Growth; A Reexamination", The Review of Economics and Statistics, May, 1984, pp. 324-329.

Katz, Michael L. and Carl Shapiro. "R&D Rivalry with Licensing or Imitation", The American Economic Review, vol. 77, no. 3, June 1987, pp. 402-420.

Kawasaki, Seiichi and John McMillan, "The Design of Contracts: Evidence from Japanese Subcontracting," Journal of the Japanese and International Economies, vol. 1, 1987, pp. 327-349.

Kinmouth, Earl H. "Japanese Patents: Olympic Gold or Public Relations Brass?", Pacific Affairs, vol. 60, no. 2, Summer 1987, pp. 173-199.

Link, A. "Productivity Growth, Environmental Regulations, and the Composition of R&D", Bell Journal of Economics, vol. 13, no.2, 1982, pp. 548-54.

Mansfield, E. "Industrial R&D in Japan and the United States: A Comparative Study", American Economic Review, vol. 78, no. 2, 1988, pp. 223-228.

Mansfield, E. "Basic Research and Productivity Increase in Manufacturing", American Economic

Review, vol. 70, 1980, pp. 863-73.

Minasian, J. "Research and Development, Production Functions and Rates of Returns", American Economic Review, vol. 59, 1969, pp. 80-85.

Miyagawa, T. Kenkyū kaihatsu shishutsu no keizai koka to seifu no yakuwari (The government's role in the economic effects of R&D expenditures), Kikan gendai keizai, vol. 55, 1983, pp. 139-150.

Nadiri, M. I. "Contributions and Developments of Research and Development Expenditures in the U.S. Manufacturing Industries", in G.M. Furstenberg, ed., Capital, Efficiency and Growth, Ballinger, 1980, pp. 362-392.

Odagiri, H. and H. Iwata "The Impact of R&D on Productivity Increase in Japanese Manufacturing Industries", Research Policy, 15, 1986, pp. 13-19.

Odagiri, H. "Research Activity, Output Growth, and Productivity Increase in Japanese Manufacturing Industries", Research Policy, vol. 14, no. 3, 1985, pp. 117-130

OECD, OECD Science and Technology Indicators Report no. 3: R&D, Production, and Diffusion of Technology, Paris, 1989.

Ordover, Janusz A. "A Patent System for Both Diffusion and Exclusion," The Journal of Economic Perspectives, vol. 5, no. 1, Winter 1991, pp. 43-60.

Hayami, Yujiro and V. W. Ruttan. "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960", The Journal of Political Economy, vol. 78, no. 5, Sept./Oct. 1970, pp. 1115-1141.

Science and technology agency, Kagaku gijutusu yōran (Indicators of science and technology), (1997)

Suzuki, K. and T. Miyagiwa. Nihon no kigyo toshi to kenkyū kaihatsu senryaku (Research and development strategy and Japanese industrial investment) Toyo keizai shinposha, 1986.

Terleckyj, N. E. "Effects of R&D on the Productivity Growth of Industries: An Exploratory Study", Washington D.C.: National Planning Association, 1974.

Wineberg, Arthur. "The Japanese Patent System: A Non-Tariff Barrier to Foreign Businesses?," Journal of World Trade Law, vol. 22, no. 1, 1988, pp. 11-22.

Yaginuma, H., K. Horiuchi, M. Nakanishi, and T. Miyagiwa. Setsubi toshi kenkyū '81 (Business investment survey '81) keizai keiei kenkyū, 3-4, Japan Development Bank, 1982.