Session IV

BARRIERS TO THE TRANSFORMATION OF SCIENTIFIC KNOWLEDGE

INCENTIVES AND DISINCENTIVES TO PARTICIPATE IN THE PROCESS OF INNOVATION: SOME INTERNATIONAL SPECULATIONS

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Introduction

This really *is* a discussion paper. It is intended to stimulate consideration of the forces at work to promote or thwart translation of outcomes of science and subsequent research and development activities into innovations.

The paper seeks to achieve its purpose through consideration, first, of the incentives and disincentives which influence various parties to the innovation process to participate in or withdraw from such processes. Such incentives and disincentives will be considered at the level of the individual, firm, industry, public enterprise, and, finally, the nation. To sharpen the discussion still further, the different forces with which such incentives and disincentives play upon the scene in several nations are compared. Usually the United States, Japan, the United Kingdom and France are considered although in some instances it is only the U.S. and Japan.

The ratings, given the "power" of incentives and disincentives, have *not* been scientifically derived. They grow entirely out of the background and experience of the author. Moreover, he is not equally experienced with each of the countries. In order of decreasing hands-on experience with innovation processes in the countries considered are the United States, U.K., France, and Japan. In terms of extent of *study* of innovation processes of these four countries, and again in decreasing order, are the United States, Japan, U.K., and France.

Science and the Process of Innovation

Innovation is a *process*. Fully elaborated, the process typically is very complex. Moreover, each specific innovation process is different and the most efficient processes are market-determined. For present purposes, it is sufficient to describe the process of innovation quite generally.

The simplest approach is reflected in Figure 1. Science is, of course, found almost entirely at the front end of the innovation process – where idea generation, invention and basic research are found. As basic science gives way to applied science which in turn transitions into technological development,

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engineering, production and marketing, the process is completed with delivery of a new product or service into the marketplace.

That science is confined to the earliest activities does not mean that scientists should be disinterested as far as subsequent activities are concerned. In fact, there is ample evidence to support the hypothesis that innovation processes are carried out more efficiently and with greater speed where those providing underlying science outputs have at least a general understanding of what must happen to those outputs if a useful product or service is to result.

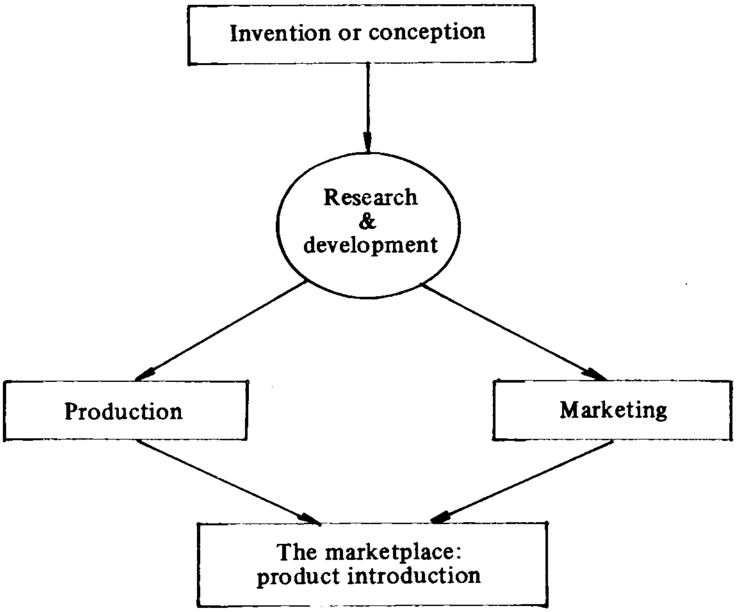

Fig. 1.

Incentives and Disincentives to Innovation

One of the most interesting – and efficient – ways to gain a basic understanding of the process of innovation is to consider the incentives and disincentives to participate in innovation. Such incentives and disincentives can be examined at various levels ranging from the individual through the firm, industry, and nation. There is also the important special case of the public enterprise.

Tables 1 through 10 list incentives and disincentives to innovation which apply in innovation processes in nations with a political system that can generally be characterized as capitalist. On the right two to four columns indicate the relative "power" of the incentives and disincentives in the United States, Japan, the United Kingdom and France.

Only a quick perusal of Table 1 is necessary to see substantial differences in relative force exerted by various incentives to innovation upon *individuals* in the

Table 1.

Incentives to innovation that influence the individual	US	JA	UK	FR
1. Increased current income	VG	M	G	M
2. Increased future income	G	M	G	M
3. Nonsalary "perks" of value (E.G., stock options, professional travel)	VG	G*	G*	G
4. Job promotion or heightened probability of promotion	G	M	L*	G
5. Increased prestige and/or responsibility	(M)	VG	VG	G
6. Job offers	(M)	L	M	M*
7. Shop rights	L	NA	N	NA
8. Opportunity to participate in the application of one's own ideas or invention	M	M	M*	M*

Legend
Influences of incentives:
VG = Very great
G = Great
M = Modest
L = Limited
N = Nil
NA = Not applicable
( ) = Range is wide
* = Often a function of the present position of the individual and other specific factors

countries considered. With regard to increased current income, this is an extremely powerful incentive in the United States and only a modest one in Japan and France. On the other hand, increased prestige and responsibility for an individual are judged far more powerful influences in Japan and Britain than in the United States.

At this stage in the analysis, it is well to make two points: First, of the nations considered, in recent years only France has had a dramatic shift in political and economic organization: it has recently become a socialist country and until *very* recently, the government has monolithically proceeded to nationalize the country's enterprises and to discourage new business development. Of late – in the last few months – the French Government has taken steps to stem the outflow of entrepreneurs. Since the vast majority of such people recognize private enterprise as the only practical means for achieving overall goals, the inability to pursue private enterprise careers has chased them away. Recognizing this the French are now trying to reverse their fortunes with regard to "high technology" activities which often require creation and development of myriad small enterprises.

Ratings for France have been assigned with the assumption that France will remain socialist and that even more of the country's production will be government-owned, regardless of short-term backsliding in a direction of capitalism. This is not a prediction; it merely reflects the way those making decisions in France with regard to innovation look at the future.

Second, something should be said about the ranking scheme in the tables. The parentheses are meant to convey that the value inside is the most typical but the range above and below that value can be quite broad – wider than in those ratings without parentheses. Regarding the asterisks, they indicate that a special condition has led to the particular rating. For example, with regard to job promotion and heightened probability of promotion, for the UK it is suggested this is a limited incentive (in sharp contrast to the U.S. and even in France). The reason for assigning such a surprisingly low value is the unusual resistance to upward social mobility still found in Britain where it remains an even greater problem than in present day Socialist France. It will not be possible here to consider in each case the reason why an asterisk accompanies the rating. Some will be considered and discussion at the conference will bring out others.

Returning to Table 1, it is interesting to compare Japan and the U.S. with regard to job offers an individual might receive as a result of participation in innovation. In the United States, generation of job offers is a modestly powerful incentive in the general case but may be much more powerful in some instances and less powerful in others. For example, if a person gains visibility as a result of participation in innovation in an industry that is declining, he may be able to attract job offers from other industries; in such a case the power of the "job offers" incentive would be greater.

Why is this incentive given such a low ranking for Japan? Primarily because there is little propensity in Japan for employees to move from one company to another, especially in those enterprises which sponsor innovation with any degree of regularity. Because of the cultural and industrial organization characteristics of Japan, job offers even for successful participants in innovation are not a usual response.

Turning now to Table 2, the focus is upon disincentives. Lack of rewards is particularly interesting. In the United States and France, if the reward structure is lacking, individuals are not likely to participate in innovation. One reason French economic performance in the future is so severely jeopardized has to do with the fact that the socialist government has acted in a way to reduce the rewards available to successful innovators.

In the United States, if an enterprise does not have a reward structure providing

Table 2.

Disincentives to innovation that influence the individual	US	JA	UK	FR
1. Lack of rewards, even if "successful"	VG	M	(G)	VG
2. Increased visability	(L)	G	(M)	(M)
3. Increased responsibility	(M)	G	(G)	(G)
4. Extra effort required to perfect the "innovation"	(G)	M	(M)	(M)
5. Likelihood of job change (E.G., new responsibilities and/or geographical shift)	(G)	L	(M)	(L)
6. Frustration (E.G., inability to advance a "good idea")	(G)	L	(G)	(M)
7. Risk of failure	(VG)	M	(G)	(G)
8. Employer attitude toward failure of an innovation process	(M)	N	(M)	(L)

Legend

Influences of disincentives:

VG = Very great	N = Nil
G = Great	NA = Not applicable
M = Modest	( ) = Range is wide
L = Limited	

significant monetary gains to successful participants in innovation, employees will not participate. For Japan, absence of a dramatic reward structure will have only modest effect on the individual. This is because of the relatively rigid compensation structure and also because participation in innovation activities (or in any others the company designates) is seen as more or less an ordinary part of the job; therefore, heightened rewards have less influence in Japan than in other countries.

Moving down the list on Table 2, it is interesting to note the similar pattern between the preceeding factor and the risk of failure as a disincentive. In the United States, risk of failure is a very discouraging factor while in Japan it is only modestly negative. The reasons are very much the same as earlier expressed.

Remaining with Table 2, employer attitudes towards failure of an innovation are seen as having virtually no impact in Japan whereas the impact is present (though sometimes small) in other nations. This stems from the fact that Japanese senior managers explicitly approve innovation processes and take sufficient responsibility for failures to shield other employees from "retribution."

Turning now to Table 3 where the focus is the firm, the material relates to positive and negative forces playing on the firm with regard to innovation. This is *not* directly related to the firm's propensity to innovate. Certainly there is some correlation between an enterprise's *ex ante* propensity and the force with which various incentives and disincentives operate, but fundamentally the issues of

Table 3.

Incentives to innovation that influence the firm	US	JA	UK	FR
1. Increased current earnings	VG	M	VG	L
2. Increased future earnings	G	G	G	M
3. Achievement of revenue growth objectives	G	M	G	M
4. Achievement of profit objectives (E.G., reduce costs, stimulate demand)	VG	M	G	M
5. Achievement of corporate diversification objectives	G	M	M	M
6. Increased market share	G	G	G	M
7. Increased multiple on stock	G	M	M	L*
8. Capital conservation (E.G., promote noncapital-intensive production methods)	L	L	M	L
9. Reduced dependence on labor	(L)	(G)	G	M
10. Availability of IR & D funds	L	NA	NA	NA
11. Meet regulatory requirements	(G)	L	(G)	L
12. Presence of regulation that heightens the probability and/or profitability of successful innovation	(G)	L	(G)	L
13. Improve recruitment results	(G)	L	L	L
14. Enhanced image	G	M	M	M

Legend

Influences of incentives:

VG = Very good
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NA = Not applicable
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* = Specific identifiable force(s) at work of special significance

propensity and measurement thereof are different from what is being considered here.

The first item presents an interesting contrast. In the U.S. and UK expectation of increased current earnings has a very great positive influence on a firm's willingness to undertake innovation; in sharp contrast, this is seen as having very little influence in France, primarily because of the growing Socialist economy, and only a modest influence in Japan. Those who provide capital to Japanese enterprises are much more long-run oriented than are those investors – individual and institutional – that so greatly condition managers in both the U.S. and UK to place what some believe to be an undue emphasis on short-term financial results at the expense of longer term achievements. There is much less contrast between the four countries when increased future earnings are considered.

With regard to heightened market share as an incentive, the influence is considerable in all four countries. What is worth noting, however, is that in the U.S. traditional measures of market share usually relate to the U.S. or, at most, to North America. Only recently have entrepreneurs thought about the market as global. In contrast, the Japanese have viewed the market in the broadest terms for as long as have the British and, to a lesser extent, the French. The latter two have been expanding their horizons beyond Europe to address the largest possible markets to realize economies of scale. But the most important point is that as managers in all countries come to see markets as global, the force of this incentive will become uniform across the world.

The incentive to support innovation because it will improve recruitment of personnel is most powerful in the United States. The contrast between the U.S. and other nations is a result of the historic social and physical mobility of people which stands in sharp contrast to other countries.

With regard to Table 4, an insufficient competitive spur has a terrible effect upon U.S. firms and, to a significant degree, upon those in the UK and France. In contrast, in Japan, even with a high degree of domestic market monopoly, firms still tend to embrace innovation as a means of achieving profit and growth. In part this stems from the Japanese having early decided their market is the world. In this way, they have converted a small competitive spur into a potentially very large one. In the process, translating the outputs of science and technology into innovations in many fields has become a way of life for many Japanese managers.

One point to keep in mind is that, while there are big differences between excuses and reasons, the former may serve amply to encourage or discourage participating in innovation. Capital shortages as a disincentive are a case in point. Often such shortages are cited as a reason for not innovating when, in fact, capital was available even if a higher price had to be paid. In the United States and UK at the present, it is difficult to tell whether capital shortage is an excuse or reason with regard to innovation not pursued; even more important, in Japan this is not a fundamental problem because of the principle means of financing Japanese enterprise. In France, the government can do whatever it wants by supporting innovative activities in nationalized enterprise.

Table 4.

Disincentives to innovation that influence the firm	US	JA	UK	FR
1. Insufficient competitive spur	VG	(M)*	(G)	G
2. Risk of capital loss	G	L	M	M
3. Capital shortage	(G)	L	G	M
4. Short-term earnings penalty	G	L	M	L
5. Insufficient period of "monopoly profits," even if successful	G	G	G	M
6. Sufficiently high returns and growth rates without assuming the risk of innovation	VG	L	VG	L
7. Durability of capital equipment on hand	G	L	G	M
8. Inelastic demand for current product(s) or service(s)	VG	L	G	M
9. Rate-of-return regulation employing a deferred rate-base calculation	G*	NA	G*	M
10. Technological integration (E.G., "lumpiness" of investment need to fit into technologically complex system)	VG	(M)	VG	VG
11. Regulation – economic or other	(G)	(M)	(G)	(G)
12. Antitrust implication of innovation	(G)	N	L	L*
13. Industrial standardization (externally or internally imposed)	(G)	(M)	(M)	(M)
14. Lack of corporate/divisional growth objectives	(M)	L	(M)	L
15. Risk or fear of "failure"	(VG)	(M)	(G)	(G)
16. Inappropriate reward structure to promote innovation	VG	L	(G)	VG

Legend
Influences of disincentives:
VG = Very good
G = Great
M = Modest
L = Limited
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NA = Not applicable
( ) = Range is wide
* = Specific identifiabl force(s) at work of special significance

It should be noted that a short-term earnings penalty is a disincentive of different "power" in the several countries but that it works consistently with the incentive of increased current income which was discussed earlier.

The sharp contrasts between the U.S. and Japan with regard to present high returns and growth rates, the durability of capital equipment on hand and an inelastic demand for current output are both striking and interesting. Fundamentally, the great differences reflect the dedication of the Japanese to exploit promising technological possibilities, especially where they lead to rapid profitable development of markets which are global. In contrast, U.S. firms tend increasingly to focus on short-term results and, where achieved, tend to be less interested in undertaking always-risky investments in innovation.

An inappropriate reward structure to promote innovation has a profound negative influence upon firms in the U.S., UK and, even now, in France. For Japan, this is not much of a problem because people tend to support innovation activities once senior management has endorsed them. They see responsibilities to the firm and to colleagues as being great regardless of the rewards. There is a very different culture in Japan reflected here.

Tables 5 and 6 consider the *public enterprise* – entities that produce services (and sometimes products), owned and operated under the government. In the U.S., UK and Japan, these usually are airports, utilities, communications companies, etc. The striking thing about how incentives to innovation influence public enterprises is that influences are very similar across all the countries (with a few exceptions).

Why should this be so? Primarily because public enterprises are highly politicized. What they do is under constant scrutiny by politicians and political institutions; therefore, public enterprises are supposed to pursue the public

Table 5.

Incentives to innovation that influence the public enterprize	US	JA	UK	FR
1. Increased revenues	(M)*	M	G	G
2. Expanded responsibilities (E.G., functionally, geographically)	L	G	VG	M
3. Increased return on invested capital	L	L	L	L
4. Improved ratings of debt instruments	G	NA	NA	NA
5. Amelioration of complaints (from customers, citizens)	(M)	L	M	M
6. Meet regulatory requirements	G	M	G	G
7. Accommodate "customer" innovation	M	G	M	M
8. Accommodate political pressures (E.G., demand for increased labor intensity in operations)	VG	G	G	VG
9. Enhance "owner's" image generally (in the community served and beyond)	G	G	(G)	VG

Legend

Influences of incentives:

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Table 6.

Disincentives to innovation that influence the public enterprize
1. Lack of competitive spur
2. Capital constraints
3. Durability of capital equipment on hand
4. Inelastic demand function
5. Absence of life cycle costing
6. Absence of explicit growth objectives
7. Absence of conventional profit-and-loss statement and balance sheet
8. Increased operating costs
9. Lower productivity, labor and/or capital
10. Innovation not required by regulation
11. "Customer" resistance to change
12. Labor content "requirements"
13. Inappropriate reward structure to promote innovation
14. Threat to "low-profile" existence

interest nations and consequently what moves them is very similar, country to country. (No analysis was carried out with regard to disincentives; the points to be made come out adequately through incentives alone.)

Tables 7 and 8 are concerned with the *industry* level. An industry is an aggregation of firms turning out more or less functionally identical outputs (or services). Sometimes such firms are in direct competition with one another (e.g., Nissan and Toyota in Japan; General Motors, Ford, Chrysler, Nissan and Toyota

Table 7.

Incentives to innovation that influence an industry	US	JA
1. Increased current earnings	VG	M
2. Increased future earnings	G	VG
3. Improve financeability	G	M
4. Increase share of GNP	M	L
5. Thwart foreign competition	VG	G
6. Promote favorable government action	(M)	G
7. Increased tolerance of industry-wide cooperation	(G)*	G
8. Increased visibility (favorable); improved image	G	VG
9. Improved recruiting results	M	L
10. Meet regulatory mandate	(G)	M

Legend

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Table 8.

Disincentives to innovation that influence an industry	US	JA
1. Lack of sufficient competitive spur (high concentration ratio?)	VG	(L)
2. Capital constraints	G	M
3. Durability of capital equipment	G	M
4. Technological integration	VG	VG
5. Standardization (externally or internally imposed)	G	G
6. Inelastic demand for industry output	G	G
7. Regulation – economic or other; regulatory process	(G)	(M)
8. Rate of return regulation and deferred rate base calculation	G*	NA
9. Fear of hurting weak competitor (especially in highly concentrated industry)	(L)	M

Legend

Influences of Disincentives:

VG = Very great
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in the U.S.). Often firms in an industry do not compete directly (e.g., electric utilities which have specific geographic boundaries allocated to them by regulatory authorities). In any event, it is more difficult to judge the impact of incentives and disincentives at the industry level than at the individual or firm level. This is another way of saying that results suggested at this point are less precise than those advanced previously.

Fundamentally, it seems that the attitudes of an industry, whether determined collectively or not, are similar – though not identical – to those of the individual firms which make up the industry. No surprise. But it is significant that many of the differences between the U.S. and Japan grow out of the fact that in Japan individual firms that make up an industry are much more likely to communicate with one another without incurring antitrust liabilities. Therefore the position of Japanese industry is likely to be expressed more explicitly than is the case in the U.S. where consensus has to be built through interpretation of signals sent out over time as a result of activities of individual firms responding to various markets.

At the level of a *nation,* as Tables 9 and 10 reflect, incentives and disincentives are more the result of cultural differences than anything else – or so it seems. Certainly this is true if "cultural" is extended to include public policies coupled with often long-standing, economic conditions. For example, consider the contrast between Japan and the other nations where increased employment is an incentive for innovation. At present, and for sometime, the U.S., the UK and France have been pursuing pro-employment policies with vigor; in Japan, however, employment has generally been at high levels, often for cultural reasons as much as for market demand reasons, and so increased employment has had

Table 9.

Incentives to innovation that influence a nation	US	JA	UK	FR
1. Increased GNP (real)	G	G	G	M
2. Enhanced productivity – any and all factors	M	G	G	M
3. Increased employment	VG	L	VG	G
4. Improved distribution of income	G	L	M	VG
5. Increased development of new enterprizes	G	N	M	VG
6. Improved U.S. balance of payments: cut imports/expand exports	VG	M	G	G
7. Improved "quality of life"	G	M	M	L
8. Increased decentralization of industry	M	N	N	N
9. Enhanced international prestige	M	G	L	G
10. Strengthened military posture	G	L	M	M

Legend

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VG = Very good
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Table 10.

Disincentives to innovation that influence a nation	US	JA	UK	FR
1. Regulation – economic, safety, environmental; regulatory process	(G)*	(G)*	(G)*	(G)*
2. Chronic inflation	M	L	M	M
3. Tax level and structure	M	L	G	G
4. Egalitarian philosophy (E.G., redistribution of income objectives)	N	L	N	G*
5. Decreased employment (E.G., from automation)	L	L	L	G
6. Natural resource constraints	L	(G)*	M	M
7. Import barriers	(M)	(G)	(M)	(M)
8. Export barriers	(G)*	NA	L	N
9. Golden fleece-type awards	(G)	NA	NA	NA

Legend
Influences of incentives:
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L = Limited
N = Nil
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little or no influence on innovation activities.

Again, consider differences with regard to improving distribution of income (i.e., making it more equal throughout society). In the U.S. this has been a considerable incentive to support innovation; in Japan this is not significant. In France, at present, the goal is central and, to the extent the country supports innovation activities, it is in the belief that innovation will improve distribution, especially if limits can be placed on how wealthy entrepreneurs can become. (Of course, the latter attitude is anti-innovation because it has been well established that the most important single motivation influencing entrepreneurs is acquisition of personal wealth. Perhaps the French will learn and, indeed, they already are doing so. As earlier alluded to, they are beginning to encourage small, "high tech" businesses.

Increased development of new enterprises is a very great incentive in France at the present time for reasons just given. At the same time, it has virtually no impact in Japan where success in innovation (however measured) is not generally seen as related to establishment of "new" firms.

The balance-of-payments issue with regard to incentives is relatively easy to deal with. In the U.S., UK and France, there are enormous pressures to improve balance-of-trade positions; in Japan the pressure is less intense because of recent history. To the extent other nations than Japan exploit innovation to redress balance of payments positions *vis a vis* Japan, Japan may place a higher priority on balance of trade aspects of successful innovation.

A strengthened military posture has been a considerable incentive for the U.S. to reach to the frontiers of technological possibility and to take advantage of what is derived in a commercial context. In contrast, Japan, with minimal defense requirements, does not have this incentive to innovation. In Britain and France, this incentive is modest today but may become more powerful in the future.

Considering disincentives, regulation appears to have about the same net effect in each of the countries. What is more striking is that underlying reasons seem to be different. Economic regulation in Japan is highly protectionist: regulated industries are protected from competition and regulation is a significant disincentive to innovate. In contrast, the U.S. is moving towards *de*regulation with a vengance which is having a depressing effect upon such industries for several reasons. First, such firms now are often unable to generate the level of profits previously enjoyed, with such profits being partially available for investment in innovation. On the other hand, deregulation has in some instances made it *possible* for firms to differentiate themselves based upon the technology employed to produce their outputs. With deregulation so new, this phase of competition has not yet been fully manifest and is now largely centered on cost-reducing activities primarily achieved through managerial rather than technological changes. (This is not to say that managerial and other forms of non-technological innovation are unimportant, only that they are fundamentally different.)

With regard to natural resource constraints, since there are so few of them in the United States, they represent a minor disincentive to innovation. In sharp contrast, Japan faces myriad natural resource constraints and this certainly has influenced investments in innovation. For example, Japan seems clearly to be reducing emphasis on innovation in those industries where large imports are required to produce outputs which are then exported in quantity. This partially explains Japanese loss of interest in steel-making, shipbuilding, and even automobile production, while it emphasizes computers, data gathering, manipulation and usage, and cosmetics.

In Britain and France, natural resource constraints can sometimes be severe but the cost of meeting shortages are generally less than for Japan. Hence natural resource constraints appear less severe and therefore less of a disincentive than for Japan.

An especially interesting potential disincentive is barriers imposed by government. In the United States, there has long been an interest in protecting technologies which have defense implications. This has resulted in some lack of interest in innovations where the U.S. domestic market was not large enough to justify the investment required. On the other hand, the Japanese so little constrain their exports that this barrier carries the designation "not applicable."

To conclude, it seems appropriate to focus attention on barriers to transfer of science-generated technologies from universities to other settings. This provides an opportunity to summarize the foregoing analysis.

Table 11 lists obstacles to transfer of technology from universities as determined from a study conducted in the United States. The relative importance of each barrier in the U.S. and Japan has been added. In many instances contrasts are sharp and in others similarities are striking. An example of the former is that lack of an appropriate reward structure is a very important negative factor in the

United States but far less so in Japan. An example of similarity is that both in the U.S. and Japan there is usually a lack of interest on the part of university personnel in converting science and technology into a form that the marketplace will find "useful." While this does not mean that such a condition is bad or good, it does suggest that if one seeks to promote technological innovation based on university achievements, this "lack of interest" needs to be overcome.

In both the U.S. and Japan, some importance must be attached to lack of recognition among university scientists – and to some extent, engineers – of what outcomes are of broad practical and commercial interest to those in the best position to exploit them. The reason this barrier is less present in Japan has to do with the generally closer relationship between Japanese industry and university.

Certainly in both countries a university's outcomes are rarely expressed in terms that promote their use in a market-oriented innovation process. But in Japan this barrier would seem lower than in the United States, probably because

Table 11.

Obstacles to the transfer of technology from universities to other settings	Imports*	
	US	JA
• Lack of an appropriate reward structure	1	3
• Lack of recognition and understanding of what is of broad practical or commercial interest	1	2
• Insufficient knowledge of the needs of others	2	2
• Results of the university's scientific, technical and engineering activities are rarely couched in terms promotive of subsequent exploitation in other settings	2	3
• Publication is all – or at least an end in itself?	3	3
• Fundamental belief in patents	2	3
• Inconsistent motivation	2	4
• Frequent lack of interest in converting scientific and technological results into "useful" form	1	1
• Infrequent interchange of persons between academic and industrial life	2	3
• Few, if any, university resources dedicated to the conversion of scientific and engineering outputs to useful form as far as external markets are concerned	2	4
• Universities rarely have an organizational element dedicated to the marketing of "technological possibilities"	2	4
• General confusion as to the "ownership" of "technological possibilities" generated in the university setting	2	4
• Universities eschew external political problems	3	4
• Faculty and staff rarely are challenged in such a way as to produce and promote readily exploited scientific, technical or engineering results	3	NA
• Faculty and staff often fear being "exploited" by big, bad private sector enterprize	3	4
• Teaching really is antithetical to doing	4	4
• University administrators often hold that anything which distracts the faculty from teaching and/or "doing" science and engineering must be inimical to the university's fulfilling its basic mission	3	4

*Imports are shown by ratings from 1 (Very important) to 4 (Little importance) and NA = Not applicable of the previously noted stress by Japanese industry on maintaining liaison with the university community.

Both in the U.S. and Japan, a great deal of attention is paid to publication of research results. At the very least, for many scientists and others on university faculties especially in their early years, publication is very nearly "all." It is essential to academic promotion and to the attainment in the United States of tenured status. With publication often an end itself, faculty frequently do not think about practical values derived from their research activities. Hence the focus on publication is a considerable obstacle to exploitation of outcomes from universities. Still, little evidence supports the contention that this is a major barrier and there is reason to believe it is often given more as an excuse than a reason for a university scientist's failure to promote utilization of research.

Many persons associated with innovation believe that if a scientific outcome cannot be patented, it must not be useful. This is a serious obstacle to innovation – more so in the U.S. than in Japan where patents are of less significance in part because of the relatively concentrated nature of Japanese industry. For every patented or patentable outcome in universities, there are many achievements which have not been patented but which would have considerable value if made a focus of innovation. Consequently it is important to place patents in their proper perspective if universities are to contribute fully.

A major negative influence on innovation present in both countries has to do with lack of interest on the part of university faculty members in promoting conversion of results into a form the marketplace will consider useful. Many academics simply eschew involvement in what they consider to be another and unfriendly world. Overcoming this problem requires perusal of Table 1 to find incentives to antidote this lack of interest.

In the United States, a significant barrier to exploitation of university technology outcomes has to do with lack of university resources available to promote conversion from technological possibility to innovation. In Japan this is far less a barrier primarily because many industries recognize the need to make such conversion so they undertake it on their own initiative rather than rely on universities.

In general, the same explanation applies to the situation where universities seldom have an explicit organization to market the "technological possibilities." Even in universities which have a "patent department," rarely is a significant percentage of the university's on-the-shelf inventory of valuable technology offered. Patents are the touchstone and this causes opportunities to be missed. In Japan, corporations are usually more active in pulling technology out of universities.

There is a considerable problem with regard to "ownership" of outcomes produced at a university. While this situation has clarified somewhat in the United States in recent years with regard to research results paid for by U.S. Government funds, there is still much confusion. Confusion leads to less transfer. In Japan there is clearer understanding as to ownership of university-generated technologies.

Faculty in the U.S. sometimes refuse to promote use of achievements because they feel they will be unduly exploited by firms that license such results. This is not as prevalent as some hold; but occasionally, it is important. In Japan this is less of a problem partially because of the more comfortable relationship between private sector entities and university departments.

One commonly held myth about university science and technology is that it is so little exploited in the U.S. because the principal job of the faculty member is teaching and those who teach cannot "do." This is such obvious nonsense that it is not a significant barrier in the U.S. or Japan.

To be sure, some university administrators in the U.S. (but not in Japan) want to guard faculty from virtually anything that is real-worldly. Such administrators often justify their behavior by advancing the idea that producing results which may be useful represents a dangerous distraction for faculty and therefore must be discouraged. In Japan, university administrators rarely hold this view. In the United States, faculty members are tending to ignore such administrators more often as they recognize the values for teaching and for their students that grow out maintaining currency with respect to the needs of industry.

A Final Word

By now, the point should be well made that those engaged in producing the raw materials from which technological innovations result must themselves have an appreciation for the down-stream use of their scientific and engineering outcomes if scientists and engineers are to promote such healthy economic and socially desirable activities. Also, there is no single general case that can be studied to gain a full and relevant understanding of the way conversion of science to technology to innovations works in every setting. It appears, however, that one of the more efficient means of acquiring knowledge of the innovation process is to study the character and force of the various incentives and disincentives to innovation that impinge upon the scene in different political and national environments. It is in this spirit that the paper is offered.

DIRECT AND INDIRECT CHANNELS FOR TRANSFORMING SCIENTIFIC KNOWLEDGE INTO TECHNOLOGICAL INNOVATIONS

Fumio KODAMA*

Introduction

It is widely believed by students of science and technology that scientific activity is the only source of technological innovation. Often, this belief is based on the so-called "process-phase model of innovation": the production of science, the dissemination of science, and the utilization of science. The process-phase model stipulates that these activities follow each other more or less sequentially.

Several empirical investigations, however, endorse this model only with reservations.

First, it is true only at the macro level and is true only in retrospect. In other words, it is not the model of causal relations.

Secondly, at the micro level of innovation, it is true in very limited cases. Michael Gibbons and Ron Johnston(1), for example, drew a sample of thirty innovations and analysed the characteristics of the information which contributed to the resolution of technical problems. They found that slightly more than one third of the information units originating from sources outside the company which had contributed to the resolution of technical problems were classified as scientific. And the analysis of the use of scientific literature revealed in over half the innovations studied (20 out of 30) that no use was made of this source at all.

Another serious defect of the process-phase model is that it ignores the inverse relationship: the stimulation of science by technology and the provision by technology of new tools for scientific investigation. D. Gazis(2) studied several cases drawn from IBM laboratories. He identified two factors as representing the most important contributions to the technology-science interaction:

(1) the combination of the two attributes of scientist and technologist in one and the same person;

(2) the revolutionary rather than evolutionary nature of the technology involved.

These findings give us a new framework which is quite different from that of the conventional process-phase model of innovation for analyzing barriers to the transformation of scientific knowledge into technical innovations.

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Therefore, the purpose of this paper is to identify channels for this transformation in the Japanese system and to analyse cases and characteristics of barriers, based on the new framework described above.

Production of Scientific Ideas

In order to describe the channels for transforming scientific ideas into innovation, we have to identify where scientific ideas are being produced in Japan. In 1978, research was conducted in 618 faculties of universities, 894 research institutes and 14,757 companies.

However, much research has little to do with the production of scientific ideas. Therefore, we can assume that the units responsible for major production of scientific ideas are universities, national research laboratories, and central research laboratories of companies. Thus, there are 349 research organizations in national universities, 89 national research institutions and 14 public policy companies, such as JNR, NTT, NHK, etc.

In order to characterize the Japanese production of scientific ideas in terms of the analytical framework for science-technology interaction described above, let us investigate when and why these three science institutions were established.

At the very beginning of Japan's modernization, under the Reformation Government in 1868, the government decided to introduce science and technology to the country in order to catch up with the West. The Imperial University was founded in 1886. From the outset, the Imperial University had the Faculties of Literature, Law, Science, Engineering, Medicine and Agriculture. The constitution of the faculties reflected the government's view that applied science was as important as pure science. In the national universities established thereafter, the faculties of applied science (i.e. engineering, agriculture, and medicine) were given an important place in their departmental structures3).

When the Imperial University system was founded, the top priority was to establish Japan as a modern nation. In other words, the government thought that the university system was indispensable for modernization. Therefore, the responsibility of the university was to promote science for modernization.

The national research laboratories of MITI can serve as examples of the Japanese conception of national research laboratories. All of MITI's national research laboratories, which were established in the Meiji era (1868–1912), were created as testing stations for products and equipment to be used in building the country's basic infrastructure. Those laboratories established in the Taisho era (1912–1926) were engaged in building the country's industrial infrastructure. Those established in the Showa era (after 1926) were intended to contribute to building the country's engineering infrastructure.

Therefore, the common goal of all of the national research laboratories founded in three different time periods was to establish science for building the country's infrastructure.

Almost all of Japan's major companies in important industrial sectors had established research institutes for basic and fundamental research by the early sixties. These institutes were organized as independent entities separate from other product-oriented research organizations. During that period, all the Japanese companies made the utmost effort to import and assimilate the most advanced technologies. Therefore, the purpose of fundamental research laboratories in the industrial sector was to support science for its role in the assimilation of technology.

In conclusion, the technological level of each time period set the agenda for the scientific investigations which were to be undertaken by Japanese scientific institutions. The requirements of modernization determined the agenda for science in the university system, the requirements of infrastructure-building set the agenda for science in the national research laboratories, and the requirements of technology assimilation set the agenda for science in the central research laboratories of companies.

Channels from University to Industry

In Japanese national universities, which perform a major portion of the scientific research conducted in Japan, no part-time consulting activity has been done for industry because professors are considered to be full-time government employees. Although there are a number of research contracts between Japanese industries and universities, the amount of funding has been relatively small and has not covered stipends[4)].

Therefore, collaboration between university and industry is indirect in nature. There are three indirect channels for transfering scientific ideas produced in universities to industry:

(1) providing industry with ample high quality engineers and scientists;
(2) supporting industry in the selection of appropriate technologies;
(3) promoting R&D intensive industries through the development and procurement of special equipment and facilities for laboratory use[4)].

The importance of the first channel is shown in the work of Gibbons and Johnston[1)]. They write, "We have distinguished between information the problem-solver obtained during an investigation and that he already possessed himself. However, it is apparent that the use of one of these sources is not independent of the information obtained from the other; both the receptiveness of the problem-solver to external sources and his approach to the task based on his own knowledge will be to a considerable extent, a function of his previous education." Based on their systematic investigation of the factors contributing to innovation, they found that the majority of problem-solvers (53%) possessed a university education (to at least the first degree level) and they identified university education as the most important source for innovation.

Japanese universities annually produce thirteen thousand science graduates and eighty thousand engineering graduates. Furthermore, technical colleges and junior colleges annually produce nine thousand and eight thousand engineering graduates respectively. In the national universities, twenty-six percent of the students are studying engineering and six percent are studying science.

Besides the ordinary channels of education, there is another direct, built-in channel for university-industry interaction and exchange of scientific ideas. In Japan, there are two ways to get an academic degree. One is the ordinary case where a student does course work and fulfills the requirements imposed by a university. The other is where an applicant submits a dissertation paper to the university and the university accepts it. Many researchers in industry get degrees through the latter method. That is, researchers working for companies write papers based on their company work. This system motivates the researchers of companies and university professors to exchange scentific ideas in a more continuous and intimate way.

As to the second channel, various advisory committees in the governmental ministries and agencies play an important role. Through these committee arrangements, university professors help the government formulate and coordinate technological development projects. A university professor is often chosen to be a member of such committees because he is neutral to the various vested interests and possesses relevant scientific knowledge.

The third channel is more important in Japan than in the US because Japan conducts less defense research. In Japan, university procurement is probably the most demanding in terms of the level of technological sophistication and the least sensitive to price.

An American journalist5) who visited Osaka University's Institute of Laser Engineering wrote, "The construction of GEKKO XII was the result of a close collaboration between the Japanese optical and electronic industries and the scientific staff of the laser institute. By using the Nippon Electric Company as the manufacturer of the laser, rather than making it by hand at the laboratory, the first steps have been taken to establish Japan as the only country with a laser fusion industry. This strategy has already paid off; the U.S. laser laboratories, including Lawrence Livermore, buy laser glass from Japanese factories."

In any of these three indirect channels described above, we see that success depends on university professors staying neutral among the various vested interests involved. Therefore, while the status of national university professors as full-time government employees is a serious barrier to their participation through direct channels (in which they would work for specific companies as consultants or principal investigators in research contracts), that status contributes in a positive way to their participation through indirect channels.

Channels from National Research Laboratory to Industry

As far as government employee status is concerned, what is true of national university professors is also true of researchers in national research laboratories. Indeed, government rules are sometimes even more restrictive for the latter. Therefore, whatever interaction exists between national research laboratories and industries must also be through indirect channels.

However, the interaction between the national research laboratory and industry is different from that of university-industry, because there are policy mechanisms to implement the collaboration. One example is the "Engineering Research Association", a relationship of limited duration. This is a joint research arrangement in which competing firms share researchers and costs and the government provides funds and tax benefits.

In many cases, the research director for an association is recruited from a relevant national research laboratory because he has the most advanced knowledge and can be supposed to be neutral among the vested interests of the participating firms. Moreover, the researchers of national research laboratories are heavily involved in the planning-work for the association and make substantial contributions to setting project goals.

In the Engineering Research Assocation for Pattern Information Processing Systems, for example, the system is divided into six recognition subsystems: printed character recognition, handwritten recognition, gray picture recognition, color picture recognition, object recognition, and speech recognition. Each firm was responsible for one of these subsystems. At one time, the participating firms were reluctant to conduct research because they thought the goals set for each subsystem were unfeasible. However, they were persuaded to do so because the researchers from the Electrotechnical Laboratory had already conducted some basic research indicating the feasibility of the goals that had been set.

Based on the analysis of technological innovations in the IBM laboratory, Gazis2) stated, "A timely and strong involvement of a scientist in the technological issues was found to be prominent. Such an involvement is, of course, guaranteed if the technologist and scientist are one and the same person."

Although a national research laboratory is not allowed to obtain research funds from industry, the government provides it with research support through project and institutional funding. The research for societal problems, for which the government is responsible, is funded by the project funding method.

Since there is a less pronounced division of labour in Japanese organizations in comparison with many other countries, one researcher is often engaged in research simultaneously supported by institutional and project funding. Therefore, exploratory scientific research and application-oriented development research are often combined at the level of the individual researcher. In such cases, the coexistence of two types of funding could lead to the "residence of the two attributes of scientist and technologist in one and the same person."

In conclusion, there is no direct channel from national research laboratories to industry. However, there are policy and funding mechanisms by which science-technology interaction is promoted.

Channels from Industry to Industry

There are three types of channels among companies in terms of transforming scientific ideas into technical innovations. All of them are related to joint research arrangements based on 1) customer-supplier relationships; 2) government initiatives; and 3) equity-holding relationships.

Customer-Supplier Relationships Joint research between public companies and manufacturers (like the joint research between NTT and cable manufacturers and that between JNR and vehicle manufacturers) is a typical example of this. In this case, procurement research by public companies can provide the manufacturers with scientific ideas that can then be transformed into technical innovations in a later stage. Similar types of joint research arrangements among private companies might involve, for example, joint research between car manufacturers and parts and material suppliers.

Government Initiatives One of the examples of government-initiated joint research among companies is the "Engineering Research Assocation" supported by MITI.

Among other things, the selection of research subjects is relevant to science-technology interaction. Since competing firms conduct research together, the subject has to be basic and common to all participants. Otherwise, many conflicts of interests might arise.

In the Engineering Research Association for VLSI (Very Large Scale Integration) development, joint research resulted in members of the association articulating their demands for I.C. manufacturing equipment and material, although none of the members was an equipment manufacturer nor a crystal supplier. This articulation of demand by the association provided equipment manufacturers and crystal suppliers with many scientific data, which they later transformed into technical innovations.

Another way to avoid conflicts among competing firms is to deal with technology of a revolutionary rather than evolutionary nature, because the development of such technology, which departs substantially from the current technical level of the firms, involves fewer conflicting interests. When this is the case, the joint research is more likely to have an impact on science[2)].

Equity-Holding Relationships Here, "joint research personnel" are drawn from within an existing, large, diverse family of companies. When, for example, a new business opportunity based on a system type of technical innovation emerges, the group companies (which are connected by an equity-holding relationship) are apt to jointly establish a new company to exploit this opportunity, (e.g., the company for ocean development established by one Zaibatsu group). The group provides the company with funds and people. Through this arrangement, scientific ideas produced for the original business of the investing companies can be integrated into technical innovation for the new business.

In conclusion, joint research arrangements among companies, whether public or private, can be an important channel for transforming scientific ideas into innovations.

Concluding Remarks

A review of the empirical investigations on science-technology interaction provides us with a new framework for the analysis of barriers to the transformation of scientific knowledge into technological innovations. By applying the new framework to an analysis of the Japanese system, we have found that the Japanese system has various important indirect channels of transformation, while there are only a few direct channels.

An analysis of indirect channels has shown us that some factors which would constitute barriers to direct channels of transformation are no longer barriers to indirect channels. On the contrary, they can be a necessary condition for indirect channels to work well.

We have found that some policy mechanisms form strong though temporary channels connecting national research laboratories to industries. We have also found that funding methods influence science-technology interaction.

An investigation of transformation channels among companies has led us to the conclusion that joint research arrangements can be an important channel of transformation in the Japanese system.

However, all the findings and reasonings described in this paper are of course based on specific experiences in specific sectors in a specific country. Therefore, further investigation is needed to construct a more general model.

REFERENCES

1) Gibbons M. and Johnston R., "The Role of Science in Technological Innovation", Research Policy 3 (1974) 220–242.

2) Gazis D.C., "Influence of Technology on Science: A Comment on Some Experiences at IBM Research", Research Policy 8 (1979) 244–259.

3) Abe Y. and Tezuka A., "Perception on Basic and Applied Sciences in Japan", in Science Policy Perspectives: US-Japan (Ed. Gerstenfeld A.), Academic Press, 1982.

4) Inose H., Nishikawa T., and Uenohara M., "Cooperation Between Universities and Industries in Basic and Applied Science", in Science Policy Perspectives: US-Japan (Ed. Gerstenfeld A.), Academic Press, 1982.

5) Bardwell S., "The Secret of Laser Fusion: The Japanese Have It!", Fusion Asia, Vol.1 No.1 1983.

BARRIERS TO THE TRANSFORMATION OF SCIENTIFIC KNOWLEDGE

Kotaro SHIMO*

1. The Distinction between Science and Technology

In ancient Greece, science was more or less identical with philosophy. It was meant to explore and clarify the principles of nature. This did not necessarily require physical labor but was fundamentally the work of the brain. Technology, on the other hand, grew out of man's everyday needs, and is mainly the product of labor, though accompanied with the work of the brain.

Although Greece claims to be the originator of science, it seems unfair to assert that the construction of the Pyramids was achieved by technology alone, without the aid of scientific knowledge. How can one label the Romans as merely "great civil engineers," while calling the Greeks "great scientists," after having seen the magnificent Roman waterways and citadels? Did not science really exist in ancient China and in medieval Japan, or was there only technology?

Leaving aside stories of the past, the distinction between science and technology seems to be less and less meaningful these days. It is needless to offer examples to prove that today, it is their interaction that enables science and technology to advance. The expression, "Transforming Scientific Ideas into Technological Innovations" seems to be too naive if this implies that science precedes technology, which subsequently turns into tangible economic results.

The fact that both the U.S. and Japan ardently strive for better collaboration between industry, academia and government to promote science and technology speaks of the futility of such a dichotomy. In other words, science and technology can better be treated as one entity in our discussion.

2. Production of Scientific and Technological Knowledge

In Japan, where contact with Western science and technology began only in the middle of the 19th century, science and technology progressed hand in hand. The idea that science was a prerequisite to technology seemed alien to the Japanese people as Japan introduced Western technology which was already highly advanced. In other words, science had been accepted as a means of theoretical analysis or explanation of long-established indigenous technologies.

However, the pragmatic approach of modern Japan may be related to the scarcity of resources for basic research which provides the wellspring of original

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discovery and invention. There is another reason suggested for the dearth of originality in Japanese discovery and invention; namely, the Japanese social structure itself. The egalitarian ideal for all stages of education, suppression of individualism under cut-throat competition for higher education, the rigid seniority system in the rank and file, life time employment – these long-established elements are the very ones that comprise the efficient "primum mobile" of the various enterprises, organizations and other groups in Japanese society; namely, consensus making, stable employment, and a strong middle-class consciousness. No doubt these characteristics have contributed greatly to Japan's conspicuous industrial achievements in recent years.

Therefore, in Japan today, the question to be answered is this: how can we introduce an appropriate education and meritocracy system which will foster the originality of individuals into our stable, long-established social structure, given the fact that it was the ingenuity of the Japanese people that cultivated such a social structure in this always highly populated country? Even great geniuses begin with imitation of their predecessors, and I think there is every reason to be optimistic about Japanese originality.

3. Communication of Knowledge

In Japan, geographically small but equipped with highly advanced communication and transportation networks coupled with multi-faceted personal ties, there seems to be no vital problem in the communication of scientific and technological knowledge. This again has to do with the homogeneity of the Japanese and their way of identifying themselves by belonging to some entity of society. Each individual seems to prove his existence by belonging to various official and private groups. These can include associations of alumni of all stages of education, hometown gatherings, academic or professional societies, study groups, committees, councils, and so on. Is this the recompense of the completely egalitarian individual for asserting his "self" identification? Such a way of living may explain why competitive enterprises can manage to cooperate fairly easily through official or private arrangements. Good communication between idividuals and enterprises makes possible collaboration between industry, academia and government even in a very restrictive regulatory environment.

4. Application

Science and technology should be utilized for the betterment of our lives. They should be mobilized to solve societal problems. A better human life means good health and comfort. Good health involves clothes, food, housing, durable and non-durable goods and all kinds of entertainment.

How are the huge expenditures for space exploration and arms development related to a better life? Space exploration may be an insatiable dream of mankind. But arms development?

Is it to defend oneself from an imaginary enemy? Americans from Russians? Russians from Americans? The West from the East, or the East from the West?

The human history of thousands of years is a history of war. The next war will cost several hundreds of million human lives. Nobody can be optimistic about the prospect for eternal peace. Are we fated to reach doomsday anyway? "Defense" (how ironical to know that no belligerent nation throughout history has ever justified "Offense") seems to claim all priority even in science and technology.

5. Barriers

Satisfaction is akin to complacency. In other words, a sound society does not stop seeking improvement. There are many obstacles to the development of science and technology in Japan today. But the most salient ones are the following.

(1) Scarcity and inefficient use of human resources

Scarcity of scientists and engineers, rigid reliance on seniority in promotion, lifetime employment, government employment regulations, the national university system.

(2) Scarcity of funds for R&D

Insufficient funding for basic research, insufficient government support.

The things to be done to eliminate these obstacles or improve existing systems are numerous and deep-rooted. Much time will be needed, but the various difficulties facing improved collaboration between industry, academics and government do not make it any less eagerly wanted or pursued. With the work of each sector complementing that of the others, such collaboration is expected to yield especially great results. Indeed, the extent to which these three sectors succeed in cooperating will have a direct bearing upon Japan's future.

Table 1. The percentage of government expenditures in several nations' total R & D efforts is as follows.

		(excluding national defense)
Japan	26%	25%
U.S.A.	47%	30%
U.K.	48%	32%
France	58%	46%
F.R.G.	43%	41%

6. Panacea?

Many of the obstacles which we must overcome in order to realize better collaboration between industry, academia and government stem from government-related regulations, such as those concerning the national university system, the status of government officials, government budget laws and regulations, etc. As these regulations all have their historic rationale, it will take time to improve the situation. However, an irreversible move towards improvement has already begun.

International collaboration in science and technology is also considered instrumental in developing Japan's future potential. The obstacles in this regard are U.S. regulations related to defense, which prohibit the transfer or not only scientific and technological knowledge, but goods as well, across national borders.

Regarding the transfer of science and technology to developing countries, the obstacles are more generic: lack of protection of industrial property (patents, copyrights, and so on), language, and the so-called "boomerang" effect.

Collaboration among industry, universities and government is only one scheme in a wide and multi-faceted world of scientific and technological activity. It is not a "panacea." It is needless to repeat that the fundamental problem is how to build up an educational and social environment where originality can flourish. Furthermore, democracy which is truly devoted to the cause of global peace is the prerequisite to such collaboration; otherwise, the fruits of science and technology will be utilized for the interests of governments rather than for the good of the people. Will we learn from the maxim that we only step up progress in science and technology when they are served in the cause of war?

THE ROLE OF TECHNOLOGY IN INFLUENCING THE INTERNATIONAL COMPETITIVENESS OF SPECIFIC U.S. INDUSTRIES

Theodore W. SCHLIE*

Introduction and Purpose

International competitiveness of a nation's industrial sector is an important topic in Washington, D.C. at the moment, particularly as it relates to Japan, world trade, and the U.S. Balance of Trade. Much of the rhetoric surrounding the "competitiveness" debate concerns issues such as high technology industries, R&D intensive trade, governmental targeting and promotion of specific industries and/or technologies, and governmental funding and coordination of R&D. Many observers attribute competitive success to technological causes and are recommending technological solutions to perceived competitive problems. As important as technology is, however, the role that it plays in international competition is complex and complementary to other factors.

The purpose of this paper is to explore the relationships between technology and international competitiveness – using specific industry cases developed by the U.S. Department of Commerce's Competitive Assessment Program. In so doing, the role that technology plays in international competitiveness will be revealed more clearly.

The Competitive Assessment Program

The Competitive Assessment Program (CAP) was operationally established in the Department of Commerce in January 1982.$^{1)}$ The primary "*clients*" of the program are policy officials in the Department of Commerce (DOC). The *objective* of the CAP is to increase the knowledge and awareness of economic policy officials regarding the medium to long-range (5–20 years out) international competitiveness of specific sectors of U.S. industry. Based on this assessment, we develop national *implications* of the assessment outcomes and Federal *policy options* to 1) change the outcomes by acting now, or 2) deal with the implications, particularly to mitigate any negative consequences.

Three features of the CAP as described above deserve mention. First, we do

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The views set forth in this paper are solely those of its author. The Department of Commerce has not reviewed this paper and takes no position on its validity or on the appropriateness of relying upon it in the formulation of Federal Policy.

attempt to maintain a long-term focus for competitive assessments, even against the continual pressure to do something about today's problems. As we like to put it, we provide a long-term context within which policy officials can make better immediate decisions. Second, we do look at *specific sectors* of U.S. industry. Although it may seem obvious to many that the international competitiveness of different industries is different in cause and outlook, the U.S. has philosophical problems in dealing with micro industry analysis and industrial policy analysis. A third feature of the CAP that we like to point out is that we deliberately do not focus only on *problems*. This is not the "threatened industry" competitive assessment program. In our view, an *opportunity* which is not exploited to the fullest is just as bad as a problem that is not addressed.

We have defined "international competitiveness" in market oriented terms – the collective decisions made by the purchasers of products or services when they choose the products or services originating in one country over those originating in others – for reasons and underlying causes which are identified, weighted, and forecast in the assessment analysis. We use quantitative analyses and qualitative opinions and judgements in pursuit of a fundamental understanding of the forces operating on a given industry and influencing its future international competitiveness.

Our approach to doing competitive assessments is very eclectic, using some of what we have learned from discussions with people from government, corporate strategic planning, academia, and the financial community. Much of our methodological development occurred during our first competitive assessment concerning the U.S. petrochemical industry, which was published in August 1982.2) Further methodological development occurred in our second assessment, which concerned the U.S. civil aircraft industry, and our approach has continued to evolve and to be refined.3)

Assessments that have been completed or are in the final stages of completion include petrochemicals, civil aircraft, advanced ceramics, international construction, and information services. Several other assessments in progress were transferred to the International Trade Administration in the reorganization referred to earlier.

Determining Recent Industry International Competitiveness – Illustrations of the Role of Technology

Part III of our generic approach to competitive assessments is entitled the "Determination of recent industry international competitiveness." Our operational definition of "international competitiveness" referred to earlier leads directly to market share indicators. When data is available, we use both percent share of world market and percent share of domestic market, including the latter measure because of the policy sensitivity to imports. Although some have tried to argue that market shares are not good indicators of international competitiveness, they have failed – in our opinion – to find better ones which work.4) Ultimately market share indicators do work, and they are usually preferred by top policy officials for the dependent variable because of the obvious trade relationship.

We then term many measures of firm or industry activity as "performance" variables – e.g.,

- Financial performance (ROI, profits, etc.)
- Growth of Shipments
- International Trade/Exports-Imports/Balance of Trade[5]
- Capital Investment
- R&D expenditures
- Employment
- Productivity

etc.

Industry performance variables in our approach are independent variables which relate to intermediary variables such as cost and/or quality, which in turn relate to international competitiveness as measured by market share. For example,

Productivity performance → cost reductions → improved competitiveness

Design technology → quality increases → improved competitiveness

Financial performance → ability to invest in new plant and equipment → cost reductions or quality increases → improved competitiveness

While we use market share measures of international competitiveness, however, we also point out that international competitiveness cannot be an absolute objective for the nation or the firm. One can go broke attempting to increase market share in the wrong way or under the wrong conditions. When we looked at the banking and financial services industry, for example, and defined the businesses[6] involved in international competition, a major competitive business during the 1970s was the granting of loans to third world and Eastern bloc countries. Gaining market share in this business during the 1970's obviously does not look like such an achievement in the 1980's.

With this qualification in mind, in part III of our generic approach we go through a three step sequence of determining and understanding recent international competitiveness.

First we determine market share measures over the past 10–20 years. The time period can be important if what looks like a trend in a shorter period is actually only a fluctuation in the longer time period. In petrochemicals we used a 10 year period (the 1970's) because of the effects of petroleum prices since the late 1960's. For large transport aircraft we used the last 20 or more years because this gives a clearer picture of relative national standing.

International competitiveness is then a trend, not a single point in time fact. It can be described in terms of increasing, decreasing, or stable. Additionally, some notion of absolute value can be used such as "dominance" – e.g., the U.S. large transport aircraft industry dominates world markets.

Second, we determine the reasons why purchasers choose the products or services they do. These are called competitive advantages and disadvantages. They are related to the classical economic concept of comparative advantage, but also incorporate the very real notion that advantages can be created – particularly by government policy – where they do not exist "naturally."7)

When one thinks about it, there are probably only a relatively few reasons why purchasers choose the products or services they do:

- Availability (in a reasonable time period) is better;
- Price is lower;
- Quality (durability, reliability, purity, flexibility, etc.) is higher;
- Marketing/distribution is better;
- Follow-on services are better;
- A Long term supply commitment is important;
- Attractiveness (consumer products) is higher;
- Socio, political, and cultural factors ranging from buy-national laws to innate feelings of patriotism being expressed in terms of buy-national behavior.

The determination of which competitive advantages/disadvantages are important in any given business can only be approximate and is cimplicated by trade-off balances and situations where there is more than one factor of roughly equal importance. Nevertheless we know that competition in commodity products is, by definition, price sensitive, that availability of machine tools coming out of this recession is a disadvantage for the U.S. industry, that a quality advantage has been an important reason for many Japanese competitive successes in automobiles, consumer electronics, etc.

Third, we determine the causes underlying the competitive advantages/disadvantages. This is the level at which most of the arguments occur and where most of the interest lies.

A few examples follow:

An availability advantage may be due to:

a) industry structure
b) capital availability and/or costs
c) distribution system
etc.

A price advantage may be due to:

a) a production cost advantage (in labor, raw materials, capital, manufacturing technology, etc.)
b) exchange rates
c) government subsidies
etc.

A quality advantage may be due to:

a) design technology
b) manufacturing technology

c) firm of government emphasis on quality control
etc.

Other potential underlying causes include federal regulations, cost and availability of educated/skilled professionals, economies of scale, government/ industry trade promotion and/or protectionism, etc.

It should be noted that a competitive advantage/disadvantage may be real or perceived. For example, a quality advantage might be perceived (and not real) because of a marketing strategy that successfully emphasized quality. Also, many causes are interactive and/or have sequential causal chains. At the root of some causes are firm management or government decisions and/or policies.

When we look at explanations for trends in recent international competitiveness in petrochemicals and civil aircraft, the role that technology plays is limited. The U.S. petrochemical industry's competitive position during the 1970s was relatively stable. Although the production process to manufacture petrochemicals is technology-intensive, and although the chemical industry performs above the all industry average in R&D expenditures, technology plays almost no role in international competition. Being a commodity product, recent competition – leargely between the U.S., Western Europe, and Japan – has been based on price. The U.S. price advantage was based on two causes: 1) lower cost fuel and feedstocks; and 2) favorable exchange rates. If one wanted to go further, lower cost fuel and feedstocks in the U.S. was due partially to a natural resource advantage over Japan and Western Europe, and partially to government controlled prices of natural gas. We could not determine with any precision the relative importance of fuel and feedstocks costs vs exchange rates, but when exchange rates reversed themselves in the early 1980's, the trade indicators started changing significantly.

Similary, technology has played little role in recent competition between U.S. large transport aircraft and the European Airbus.[8)] When one looks at the evolution of the civil aircraft industry, European technological contributions to and participation in this industry have historically been strong. It was the development of the large transport jet aircraft that largely gave the U.S. its dominant position in this market, particularly during the 1967–75 period when U.S. world market share rose above 90%. The recent decline to a 70–80% share roughly returns the U.S. position to what it was doing the 1950's and most of the 1960's. Most of this decline, However, has been concentrated in a single market segment – the twin-engine, medium range, widebody aircraft.

Although quality is certainly a necessary feature of aircraft, recent competition in large transports has been based principally on price, or on the total economic package that the seller is offering. In addition to the sticker price of the aircraft, financing arrangements have been particulary important, as have been ancillary aspects of the deal related to counter trade, loans for airport improvement, and other forms of economic assistance. The advantages that Airbus has enjoyed in third country markets in this regard have one principal underlying cause – the determination of European member governments to maintain a viable civil aircraft industry. This determination has expressed itself at various times in the form of funding development costs and subsidizing production costs, subsidizing export credits, and using a range of economic incentives and political pressures to influence sales. (Airbus has also taken advantage of U.S. liabilities in foreign policy, national security export controls, and a natural tendency of customers to want to keep competition alive in large transports manufacturing.)

Despite their obvious importance as a precondition to a successful marketing effort, technology and aircraft performance have not played a decisive role in recent head-to-head sales competitions. Both U.S. and Airbus aircraft have incorporated available technology in materials, structure, aerodynamics and power plants. Over the years, U.S. aircraft have enjoyed a reputation of technological superiority, but the prevalent perception today is that whatever technological gap existed before has now narrowed to insignificant proportions.

In another civil aircraft business, the commuter transport, the U.S. does not have an independent new entry[9)] in the larger-size (20–60 seats) models which are increasingly being sold to regional and commuter airlines. Price and operating cost advantages give foreign competitors a perhaps unbeatable lead in this business. Ironically, potential U.S. advantages in technology are neutralized in this market by the limited performance requirements for short hauls.

Identifying and Evaluating Trends and Driving Forces – Illustrations of the Role of Technology

Part V of our generic approach to competitive assessments is to identify and evaluate trends and driving forces, internal and external to the industry, which, over the next 20 years, have the potential for significantly affecting international competitiveness. Some of the trends/forces we always look at include the plans and strategies of foreign governments to support or promote their domestic industries, world demand growth and market substitutions, and developments in technology.

The plans and strategies of foreign governments – at least to the extent that information is available – often center around technology development. Japanese involvement with existing manufacturers of both airframes and engines in multi-national ventures concerning technology development and production is well known. The plans and strategies of Saudi Arabia, the Persian Gulf states, Indonesia and other hydrocarbon rich countries in establishing domestic commodity petrochemical production, on the other hand, mostly envision a turnkey transfer of the most modern foreign technology. Their strategies focus on the exploitation of indigenous natural resources, in most cases with foreign participation.

Technology can also play a role in world demand growth and market substitution trends. When we looked at downstream specialty chemicals and materials, for example, we could forecast continued substitution of composites and engineering plastics for metal and wood-based materials because of advances in materials science and technology. Large transport aircraft presented an interesting aspect of the substitution effect caused by a technology external to the industry – the effect of advances in telecommunications technologies (lower cost systems for telephone communications, electronic mail, video teleconferencing etc.) on business air travel.

Air passenger studies indicate that approximately 50% of air travel is for business purposes. This business segment of the passenger market is of particular importance to the airlines – and therefore to the large transport producers – because it is the fullfare, bread and butter of their revenue base. Marginal revenue can be gained from special fares and discounts aimed at the leisure traveler, but the business traveler is crucial.

The consensus of industry forecasts for air travel demand is that annual growth rates will average between 5–7% through the mid 1990's. When asked about the future impact of telecommunications on air travel, a typical response of aircraft and airline industry representatives is that there will always be the need for face-to-face communication. They argue, for example, that what is often lost at meetings conducted electronically is the group dynamics required for development of a consensus – something that is more readily achieved in face-to-face meetings.

Businessmen travel for a variety of reasons, however: to make decisions, to market to customers, to attend training courses, to attend meetings where ideas are exchanged and/or plans made, etc. They also travel because they like to. ("Management perquisites" was the reason given by one respondent when questioned on this topic.) Face-to-face communication is more crucial for some purposes then others. There may be little question that business air travel will continue in situations where face-to-face communication is necessary or desirable, but we believe this expense increasingly will be affected by the firm's need to hold down costs and by the increasing number of low cost telecommunications alternatives.

We are supported in this view by discussions we have had with airport hotel chains – domestic and international – which are planning or installing teleconferencing facilities, and with major corporations who are implementing internal telecommunications systems. They have studied the economics of telecommunications services in great detail (e.g., the effect on the one-day versus the overnight trip), and in general would express the belief that telecommunications will cut into future business air travel, but how greatly is not predictable at this time.

The direct effects of technological developments on future international competitiveness are always an important consideration, but do not always dominate the future. In commodity petrochemicals, we looked at the development of alternative feedstocks (synthetic gas, biomass), of new catalysts, of further energy conservation, etc., but nothing even remotely in sight appeared to be able to overcome the fuel and feedstock advantage of the hydrocarbon rich countries10) – particularly when most of their industry is being developed in joint ventures with firms from the U.S., Western Europe, and Japan who presumably would be developing these technologies and transferring them to foreign partners.

The situation with future technology developments for civil aircraft is more complex. There is little doubt that major advances in technologies related to aircraft performance will be made over the next 20 years. These prospects include advances in engine component materials, in the use of composite materials (even in large primary structures), in propulsion systems (such as propfan engines), in avionics guidance and control systems, in aeronautical design and surface technology, etc. There is little question that the U.S. is generally strong in these technologies. Although there are specific fields where the U.S. may be lagging behind other countries, there is little concern that our industry will not have access to the most competitive technologies available.

New technologies are developed for some purpose related to the performance of the aircraft. Advances in composite materials are being driven by the need for fuel efficiency. Jet fuel costs form the largest single item of airline operating costs, and potential weight savings in the body of the aircraft offer substantial cost advantages. Advances in engines are also being driven primarily by fuel efficiency, with some concern also for increasing durability and lowering maintenance costs. Advances in avionics and/or controls are being made for a number of reasons. First of all for safety, but also for lowering fuel costs through more efficient load distribution and flight handling, and for lowering labor operating costs.

In the civil aircraft assessment, these advances were clustered together under the heading of "Technology Push." In order to determine the strength of the technology push, however, one must consider the performance benefits in proportion to the costs of applying and incorporating the new technologies. There appears to be little doubt that a significant incorporation of these technologies in a next generation technology large transport aircraft would increase already huge development costs. Significant R&D, engineering, and testing problems remain for the individual technologies; incorporating them into an aircraft-engine design configuration with attendant systems effects presents potentially significant increases in developments costs.

Unlike the assessment of commodity petrochemicals, there was no single variable, such as fuel and feedstocks costs, which dominated the future international competitiveness of large transport aircraft. In order to handle the multitude of variables not included under technology push, we developed a structure which also included variable clusters called "Market Pull," the "Airline Purchase Decision," and the "Manufacturers' Launch Decision."

From the interactions of these variable clusters, a range of outcomes were defined along the dimension of the degree to which new, next generation technology large transport models replace existing models during the 1990s. At one end, the interactions result in a convergence of forces leading toward conditions under which *no* next generation models are launched – the "Current Competitiveness Continuation" scenario. At the other, the convergence of forces leads to conditions under which *all* current models are replaced by next generation aircraft during the 1990s – the "Internationalization of the Industry," scenario.

The above discussion on technology push affects all of the other variable clusters to greater or lesser degrees. Under "Market Pull," the relationship between passenger demand and the improved performance-higher cost resulting from the application of new technology must be considered – how much more is the passenger willing to pay in fares for improvements above today's performance in speed, range, safety, comfort, etc.

The Airline Purchase Decision technology/performance-cost trade off issue concerns the ability of airlines to pay for more expensive next generation technology aircraft. The decision to purchase large transports is a major, complex determination and a significant investment decision for any airline. New Boeing 757s are reportedly selling for more than $30 million, 767s for $45–50 million; current models of a new 747 cost more than $80 million. Although some foreign airlines may place orders for only two or three aircraft, U.S. airlines usually order 10 to 30 or more, which multiplies the total price into the hundreds of millions of dollars. The initial purchase price of new models is likely to increase in the future – significantly for next generation technology aircraft. As this occurs, the availability and cost of capital assume even more importance in airline decision-making. As indicated earlier, a major driving force in technology advances and the purchase of large transports today is the need to reduce fuel costs. A key question which airlines must address is whether the marginal benefits in fuel efficiency from further advances in engine and materials technology will be worth the marginal costs necessary to develop and commercialize them. Ironically, if the trend in fuels cost is downward rather than upward, the ability of airlines to purchase new aircraft through increased revenues increases, but the major reason for such purchases – greater fuel efficiency – correspondingly decreases.

In recent years, U.S. airlines' cash flow and profits have been at record lows. Economic deregulation, which has been one source of problems for the industry, has coincided with a period of significant recession, greatly restricting U.S. airlines' cash flow and their ability to finance the purchase of new aircraft.

The key factor in the Manufacturer's Launch Decision – and, indeed, in the international competitiveness of the industry – is the size and degree of risk involved in the development and production of a large transport aircraft. Development and initial production costs for current models are very high; perhaps $2–3 billion of negative cash flow that has to be carried ten or more years before break-even is reached. The economic risk involved in the development of a new model large transport is great – perhaps the greatest of any industry.

The technical risks for models using *present* generation technology are relatively manageable, but one can expect that both the economic and technical risks associated with the launch of a new large transport will increase significantly for aircraft using next generation technology in the 1990s. In real terms, development costs would undoubtedly be significantly higher, thus increasing the required purchase price, payback period, and the number of units sold necessary to reach break even. There are technical risks any time that new technologies are tested under the high performance conditions required to operate in a flight environment. Many of these risks may be reduced through the performance of R&D, but they will remain higher than with present generation technology until next generation technology becomes used in practice.

One can also identify technological advances occurring external to the civil aircraft industry that might have direct impacts on future international competitiveness. In particular:

- the development of supercomputers able to achieve magnitudes of increased performance in storage and data processing over today's state-of-the art;
- the development of supersoftware, including artificial intelligence, able to handle incredibly complex design simulations and manufacturing processes; and
- the application of the above two developments into computer integrated automated design and manufacturing operations.

We already have some idea of the utility of computer aided design and computer aided manufacturing (CAD-CAM) as applied to products such as automobiles or household appliances over the next 20 years. These developments will revolutionize the field of manufacturing operations management – economies of scope will replace economies of scale; standardization will give way to customization; the learning curve will flatten; balanced, constant flow assembly lines will give way to production on demand, and inventories will decline; management will be data/information intensive and will be the management of constant change; etc.

It may take a leap of faith, however, to envision an incredibly large and complex product like a large transport aircraft being developed and produced under the following conditions:

- With immense amounts of design and test data stored in a computer, and with adequate simulation capability, the producer is able to provide instantaneous aircraft designs in response to unique customer requirements:
- Following confirmation of the design decision, instantaneous instructions are provided to standardized parts, components, systems, and subassembly suppliers, and to customized parts, components, systems, and subassembly manufacturers;
- This is followed by automated scheduling, materials handling, and quality control of the large transport assembly.

There are obvious problems that will have to be overcome or resolved if such a vision is to be achieved. The hardware and software has to be developed, for example, also the design/test data base, the simulation models, etc. FAA certification of an aircraft design developed under such conditions will be a problem, as may be passenger acceptance. Tooling, inventory control, parts supply, etc. – the enormity of the manufacturing process for large transports will produce added difficulties. The opportunities inherent in such a vision are also obvious, however, and the nation that is able to develop this design and manufacturing technology first will have an overpowering economic advantage over its competitors.

These discussions of the role of technological trends and forces influencing future international competitiveness illustrate that technology is only one of many factors involved in the next step of a competitive assessment.

Assessing Future International Competitiveness – Illustrations of the Role of Technology

Part VI of our generic approach is to develop the actual assessments of U.S. international competitiveness. This step of the approach involves a creative synthesis of the kinds of information discussed earlier, and there is no way to formally describe how this happens. If information is available, we attempt a "technology assessment" in this section, which includes:

- identification of the technical directions that different countries appear to be emphasizing;
- comparative evaluations of technological state-of-the-art (strengths and weaknesses) among competing countries; and
- forecasts of future technological progress and implications for international competitiveness

In general, the U.S. is still the world leader in R&D and technology development – although other countries are making a concerted effort to catch us – but not necessarily in technology application. Even then, technology leadership does not always determine international competitiveness.

For commodity petrochemicals, our assessment was that the U.S. would gradually lose market share over the next 20 years to the hydrocarbon rich countries[11)] and that their ability to price their product to sell out would keep downward pressures on world prices and further depress U.S. (and West European and Japanese) industry earnings. We found no technological fixes that could outweigh the advantage in fuel and feedstocks that the hydrocarbon rich countries enjoy. People may differ in their opinions of how fast the hydrocarbon rich countries can bring their plants on stream, since many of these countries face infrastructural, personnel, and other social problems in implementing their development plans, but these will affect the timing – not the ultimate nature of – the result.

If there is a problem for the U.S. in commodity petrochemicals, however, there is great opportunity in downstream specialty chemical businesses such as engineering plastics and composites. These high value-added downstream products are where future competition between the U.S., Japan, and Europe will focus in the materials area. U.S. strengths in technology, industrial infrastructure, entrepreneurial initiative, and a large domestic market can be to our advantage in the future, but only if the industry moves forcefully in this direction now and does not squander top management attention in efforts to somehow save the commodity business.

In civil aircraft once again, the assessment was more complex. Recalling the earlier independent variable clusters, their interactions – according to our structure – result in a continuum of scenarios along the dimension of the extent to which new models of next generation technology large transports will be developed and produced during the 1990s. At one extreme of this continuum is a scenario resulting from the convergence of variables toward conditions under which *no* new next generation technology models are developed in the 1990s; at the other extreme is a scenario resulting from the convergence of variables toward conditions under which next generation models replace all or most of today's models during the 1990s. In between these extremes there are several gradations along the continuum where *some* next generation models would be developed and produced. We refer to these scenarios as the *Continuation of Current Competitiveness* scenario, the *Internationalization of the Industry* scenario, and the *Somewhere-Inbetween* scenario.

Under the Continuation of Current Competitiveness scenario, no new models other than – perhaps – a 150-seat, medium-range aircraft are developed. If a strong market requirement for next generation large transports does not materialize, if development costs for next generation technology applications go higher than anticipated, if aircraft management becomes conservative, if domestic airlines continue to experience cashflow problems, if jet fuel prices remain stable or decline, etc. . . ., then this scenario is not implausible. Under it, Airbus is limited to two or – if the A-320 is developed – three models, plus potential derivatives, and an opportunity probably does not exist for Japan to enter the market. The comparative strengths of the U.S. civil aircraft industry vis-a-vis Airbus under these conditions appear to be substantial. U.S. companies have an existing "family" of aircraft that largely cover the range-seating capacity spectrum for large transports. The development costs for this family have already been made. Taken together with existing recognized strengths in world marketing, distribution, and maintenance-service networks, in R&D and manufacturing technology, and in ability to flexibly and immediately respond to change in demand markets, we believe the U.S. industry will perform very well competitively under these conditions. Airbus Industrie would continue to be a major competitive force, but unlikely to increase its current would market share substantially. In terms of financial performance, U.S. companies would likely be well off under this scenario. Sales would come primarily from existing product lines, moving further and further toward or past break-even. It would be an industry, however, – at least on the civil side – considerably less technologically dynamic than at present.

The Internationalization of the Industry scenario is at the opposite extreme of the continuum. If market demand for air transportation and next generation aircraft exceeds expectations, if technology advances further – or its applications appear less costly – than anticipated, if aircraft management retains "the right stuff," if the airlines rationalize their industry and fare structures, if jet fuel prices continue to increase, etc., then intense competition in the development and production of next generation large transports could occur across the spectrum of range-seating capacity market segments.

Under these conditions, it is likely that the present trend toward risk sharing and "internationalization" in the industry will continue and intensify. By "internationalization" we mean the forming of consortia of firms from different countries as partners, subcontractors, or suppliers to fund and carry out the development and manufacture of a large transport model line.

There are two complementary motives behind this trend: *risk sharing* and *marketing*. Individual companies may no longer be able to afford to take the entire risk of running up high development costs given market and technical uncertainties. This motivating force can only become stronger for the development of next generation models in the 1990s. Governments which desire to establish and build their indigenous aerospace industries will be more likely to favor the purchase of an aircraft in which a national enterprise has had a piece of the action. The technical ability to operate (and successfully assemble an aircraft) under these international conditions, has been and will continue to be greatly enhanced by advances in telecommunications and CAD-CAM technologies.

Competition under this scenario would occur first in "signing up" international partners and subcontractors in a large development venture, and only later in marketing the finished aircraft. The nature of this competition would resemble political coalition building in which alliances may become stabilized or may continually shift and change in response to new models being developed and changing market and political conditions. Such a competitive environment would be very dynamic.

Our basic assessment of the competitiveness of the U.S. civil aircraft industry under this scenario is also positive. A key strength of the U.S. aircraft industry is its recognized ability to respond quickly and strongly to a constantly changing environment of market signals and technological opportunities – more quickly and strongly than can the multinational Airbus or could a new national entry from Japan, which would have to build up advanced design, development, manufacturing, and worldwide service maintenance operations.

Under the conditions we have assumed for the internationalization of the industry scenario, capital should be available from private markets to sustain the development of next generation large transports by U.S. manufacturers. Development capital subsidized or provided by European or Japanese governments would give Airbus and Japanese manufacturers an important advantage over U.S. manufacturers, but in the dynamic environment postulated under this scenario we do not believe such support will be great enough to overcome U.S. advantages. The European Airbus won't necessarily go away, but neither will it be able to significantly increase its world market share. Japan may emerge as an independent competitor in large transports, but it's hard to start up in a very expensive field when things are moving so fast, and we feel it is more likely that Japan would increase its partnership share in U.S. or Airbus aircraft.

The Somewhere inbetween scenario is defined at that point on the continuum where the most serious threat from foreign competition facing the U.S. large transport business during the 1990s will occur. At this point the interactions of the previously described variable clusters do not converge, or converge toward conditions under which conflicting or uncertain decisions have to be made regarding the development and manufacture of next generation technology large transports. Under these conditions, the provision of state subsidized or state supplied development capital by European governments, or the well-known targeting policies of the Japanese government, may seriously threaten the competitiveness of the U.S. industry.

If market demand for air transportation grows (but not as much as expected), if new technological advances occur (but cost substantially more to apply), if aircraft management becomes a bit more cautious and concerned about impacts on stockholder investment values, if airlines successfully restructure routes but still experience cash flow problems, if the price of jet fuel hovers about where it is with no clear direction of up or down, etc. . . ., determined and concentrated efforts by governments in the decision to go ahead and launch a new or next generation large transport could have a significant impact on competition.

Under these conditions, capital markets in the U.S. might be very wary of financing development costs that might go as high as $4–5 billion. Airlines would probably be very hesitant to commit themselves to large orders. Manufacturers would agonize over the trade-offs between the benefits received and the degree of management control lost from international participation in risk-sharing.

If the U.S. industry should be mired in uncertainty under such conditions, Europe and/or Japan could achieve significant gains. Airbus in particular might do very well. Government-owned or controlled airlines in Europe, for example, might be persuaded to commit themselves to launch orders for a next generation Airbus family. Government development capital could then be provided which would reduce risks significantly. Finally, sales to third country and even U.S. airlines could be subsidized in order to ensure a minimum market and production line. With a world marketing and support/maintenance network already in place, Airbus would be well positioned to capture world market share.

Japanese prospects would also appear to improve. The Japanese approach to industrial policy would appear to be particularly well-suited to targeting a specific segment of the market for a next generation large transport, for organizing and subsidizing an industry consortium for this purpose, and for entering the market with a low-priced, quality product that captures significant world market share.[12)]

To summarize, if the environment of the 1990s turns out to be more like the uncertain somewhere inbetween scenario than either extreme, we believe the chances for a decline in U.S. competitiveness in large transports are greater. The biggest competitive threat would come from the European Airbus consortium, but a potential competitive threat might also appear from Japan.

In assessing U.S. international competitiveness under the conditions of breakthrough applications in super computers, super software, and computer integrated manufacturing, the significance of the potential Japanese threat becomes much more apparent. Although the U.S. aircraft industry is currently regarded as being a world leader in CAD-CAM applications, it is Japanese industry which is taking over world leadership in the development and application of general industrial robots. Moreover, they have targeted both supercomputers and artificial intelligence as high priority technologies of the future, and have implemented government funded programs to stimulate and coordinate R&D in these fields.

Summary

In this paper, I have discussed some of the ways in which technology interacts with other variables in the explanation of recent international competitiveness of specific U.S. industries and the assessment of future international competitiveness. Examples from petrochemical and civil aircraft assessments are used to make the point that technology is not always an important – let alone dominating – factor in assessment outcomes, and even when it is, it is only one of several variables that interact in complex ways and defy easy and general categorizations.

REFERENCES

1) The Competitive Assessment Program was orginally located in the Economic Affairs part of Commerce, but was moved to the International Trade Administration in January 1984. The competitive assessment activity will now be carried on under the Assistant Secretary for Trade Development in a reorganized structure that is still evolving. The information contained in this paper on the CAP pertains to the 1982–83 period.
2) "A Competitive Assessment of the U.S. Petrochemical Industry," Office of Competitive Assessment, U.S. Department of Commerce, August 31, 1982.
3) "A Competitive Assessment of the U.S. Civil Aircraft Industry," Industry Analysis Division, U.S. Department of Commerce, March 1984. See also "Generic Approach to the Conduct of Full-Scale Competitive Assessments," Office of Competitive Assessment, U.S. Department of Commerce, December 13, 1983. Portions of this paper are taken verbatim from sections of the petrochemical and civil aircraft assessments, which were written by this author.
4) Many people have argued for profit or return on investment oriented indicators of international competitiveness, but such an approach does not take into account long-term strategies to forego short-term profits in order to capture market share and – hopefully – longer term profits. Others have argued for a composite indicator composed of five or more variables. See, for example, Beatrice N. Vaccaro and Patrick H. MacAuley, "Evaluating the Economic Performance of U.S. Manufacturing Industries," *Industrial Economic Review*, Summer 1980, U.S. Department of Commerce. Unfortunately, outside of the fact that composite indicators are difficult to use in practice, one also finds that many independent variables are being caught up in the dependent variable measure.
5) Note that trade measures such as world export market share are not equivalent to market share!
6) A "business" in our approach is a major product line-market segment which would be the subject of a unique corporate strategy – e.g., in the automobile industry, there would be family car, sports car, luxury car, off-the-road vehicle, etc. businesses. Competitive assessments are actually conducted at the level of the business, not the industry.

7) "A brief discussion at this point of the term 'competitive' vs. 'comparative' advantage/disadvantage mirrors the earlier discussion of competitiveness vs. performance. Lying at the heart of the difference in terminology is the notion that *comparative* advantage is somehow 'natural,' but really this reduces to the fact that comparative advantage is accepted and understood in classical free market economic theory as the 'rational' basis for international commerce based on performance and ROI. The world isn't always 'rational,' however, and the term *competitive* advantage has been used to connote governmental intervention in international commerce to give domestic industries real – if 'unnatural' – advantages which, over time, can be transformed into a comparative advantage." Theodore W. Schlie, "The Competitive Assessment Program," paper presented to the seminar on U.S. Microelectronics Industry and Public Policy sponsored by the Center for Science and Technology Policy, New York University, April 30, 1980. This discussion is based on concepts presented by John Zysman and Laura Tyson – ". . . it is first necessary to distinguish between the notions of comparative advantage and competitive advantage. Comparative advantage refers to the relative export strength of a particular sector compared to other sectors in the same nation and is usually measured after adjusting for market-distorting government policies. For the purposes of our discussion, competitive advantage refers to the relative export strength of the firms of one country compared to the firms of other countries selling in the same sector in international markets. According to this interpretation, the competitive advantage of the firms of a particular country in a particular sector may be the result of that country's absolute advantage in that sector. In contrast to the usual nation of absolute advantage, however, the notion of competitive advantage allows for the presence of economic policies that help or hinder the international performance of different firms. Thus the competitive advantage of the firms of a particular country in a particular market may be the result either of real absolute advantage or of policy-induced and hence distorted absolute advantage. Indeed, policy-induced advantage can become real absolute advantage over time." John Zysman and Laura Tyson (ed), *American Industry in International Competition*, Cornell University Press, 1983, page 28.

8) Our analysis does not include the introduction of the new Boeing 767 and 757 models.

9) Fairchild has a joint venture with SAAB of Sweden in this aircraft class.

10) In order to understand the importance of fuel and feedstocks to international competition in petrochemicals, the economics of petrochemical production must be considered. The petrochemical industry is unique in that the basic raw materials from which petrochemicals are formed are hydrocarbons – petroleum, natural gas, and natural gas liquids. It is the most energy intensive of all manufacturing industries. Fuel and feedstocks now account for 60–80% of total production costs of primary commodity petrochemicals. This percentage of total production costs decreases as petrochemical processing moves downstream, but fuel and feedstocks remain the dominant production cost variable, accounting for 35% and up of total production costs.

The "hydrocarbon-rich countries" – e.g., Saudi Arabia, the Persian Gulf States, Indonesia, Canada, Mexico, etc. – have large quantities of natural gas presently being wasted – flared – or underutilized. Unlike liquid petroleum, natural gas and its liquids are difficult to transport in their raw form. The primary ways to to this are by pipeline or in liquid form, both requiring extremely high capital expenditures. The other way to transport natural gas is to process it into commodity petrochemicals, and thus capture the value added as well. The world price of fuel and feedstocks, which is operational for the U.S., European, and Japanese industries, does not have the same relevance to petrochemical production in Saudi Arabia. There, the practical choice comes down to using available gas for petrochemicals or flaring it, whatever the world price may be. The effective cost of feedstocks from flared natural gas in places like Saudi Arabia is the cost of installing the gathering system.

The governments of the hydrocarbon-rich countries have made it plain that they will supply natural gas feedstocks to their plants at prices that will ensure competitiveness in world markets. There is no way that the U.S., European, or Japanese commodity petrochemical industries will be able to compete with them on this basis. The principal limits to the ability of these countries to penetrate world markets will be their infrastructural and financial resources.

11) For some individual petrochemicals, the loss of competitiveness is not so gradual. The U.S. ammonia/fertilizer industry is already in a "crisis" situation caused by foreign imports.

12) It is well to remember, however, that large transports are not the same business as steel, autos, or semiconductors. Japan, for example, does not have a sizable domestic market in large transports which it can protect to get it very far down the learning curve, nor can it market aircraft the same way it markets other commodity products. Nevertheless, Japanese intentions to enter and excel in the civil aircraft industry are explicitly stated in the MITI "Vision for the 1980s." Moreover, their recent and current initiatives in joining up with aircraft and engine development ventures should temper any overconfidence in Europe or the U.S. about their future ability to repeat their sucesses in steel, autos, and semiconductors.