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Case Studies

Transfers of United States Aerospace Technology to Japan

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THE RAND CORPORATION

Economists have usually regarded the situs and dispersion of technology as exogenous factors, the concern primarily of historians [15]. Although differential endowments of technology are of fundamental importance for the central body of economic theory and doctrine, there has been little attention given to the question of how these differences are established or modified. This situation is changing, however. Many recent theoretical models and empirical studies incorporate the transfer or diffusion of technology,[1] but so far only a few case studies have explicitly treated the expected benefits that create a demand for someone else's technology, and the process and costs of meeting this demand [3].

This paper deals with the last topic, the process and the attendant costs of transferring technology among companies in highly developed economies. It is a case study of four interfirm transfers to Japan in the 1950's and 1960's [6, 20]. Interfirm transfers are one of many types of international technology transplantation that are occurring with increasing frequency, but the histories of these four transfers illustrate some

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NOTE: The views expressed in this paper are those of the authors. They should not be interpreted as reflecting the views of The RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors.

[1] Examples include: Behrman [4]; Gruber, Mehta, and Vernon [5]; Hirsch [7]; Keesing [13]; Mansfield [14]; Nelson [17]; Nelson, Peck, and Kalachek [16]; Spencer [20]; Vernon [22]; U.S. Department of Commerce [21].

general considerations relevant to all types of international movements of technology.

During the 1950's and 1960's there were numerous international aerospace manufacturing programs, many of them involving the production of complete aircraft, as can be seen in Table 1. From 1950 to 1967, more than 10,000 sophisticated aircraft, with a market value of over $5 billion, were produced by firms under license from the original designers.

During this period, Japan was particularly active in acquiring aerospace technology, most of it from the United States. Their skill in doing so confirmed the reputation the Japanese have had for over a hundred years as skilled importers of technology; but economists have too often merely expressed their admiration for Japanese astuteness and left the matter there. Sociological and cultural factors are important, of course, but the relevant issue is how the Japanese actually formulate plans and proceed to acquire technology. The aircraft manufacturing programs to be analyzed here show that the process involves difficult decisions about what and how much technology to acquire and the process by which it is acquired. Correct decisions importantly affect the success and costs of international transplantation of technology.

SOME CONCEPTUAL CONSIDERATIONS

We often speak of technology being transferred or knowledge migrating, but are seldom precise about the process involved.[2] Precision is important because technology as an abstraction cannot move—things and people are transferred.

Technology can be transferred in two basic forms. One form embraces physical items such as drawings, tooling, machinery, process information, specifications, and patents. The other form is personal contact. Put simply, knowledge is always embodied in something or somebody, the form being important for determining the transfer process and its costs. The process is simpler if knowledge is embodied in purely physical

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[2] Technology is knowledge or information that permits some task to be accomplished, some service rendered, or some product produced. Conceptually, technology can be distinguished from science, which organizes and explains data and observations by means of theoretical relationships. Technology translates scientific relationships into "practical" use.

TABLE 1

International Production of Aircraft Under License, 1950–67

Location of	Location of	Bombers		Fighters		Other Military		Heli-copters		Civilian Transports		Total	
Licensor	Licensee	No.	$ Million	No.	$ Million	No.	$ Million	No.	$ Million	No.	$ Million	No.	$ Million
U.S.	Europe	–	–	1,393	2,046	100	3	2,183	294	–	–	3,676	2,343
U.S.	Other	–	–	2,532	1,002	568	241	570	94	–	–	3,670	1,337
Europe	U. S.	403	484	–	–	–	–	–	–	278	148	681	632
Europe	Europe	–	–	899	365	669	109	–	–	–	–	1,568	474
Europe	Other	48	372	669	109	–	–	100	20	44	66	861	567
Total		451	856	5,493	3,522	1,337	353	2,853	408	322	214	10,456	5,353

Source: R. E. Johnson and J. W. McKie, *Competition in the Reprocurement Process*, The RAND Corporation, RM-5657-PR, May 1968, p. 24. For data on the underlying programs, see Appendix C of the same study.

items. If it is embodied in people's expertise, a personnel transfer may be necessary—often in the form of a technical assistance program. Within a single organization, the process may be more informal: people simply meet to talk or work together.

In any case, the ease and cost of transfer hinge on the industrial skill the recipient already possesses. A firm skilled in the manufacture of some general line of products—voltage regulators, let us say—will probably have little trouble in mastering the technology for a new regulator; in turn, the transferring firm will probably find it easy and inexpensive to impart the required information. The opposite will hold if the transfer entails a substantial advance in the technical level of the new producer. This fact has led us to distinguish among types of information that may be transferred. We refer to these as general, system-specific, and firm-specific technologies.

General technology refers to information common to an industry, profession, or trade. At one extreme this category includes such basic skills as arithmetic, and at the other such specialized skills as blueprint reading, tool design, and computer programming. The same general knowledge is possessed by all firms in an industry and hence is the ticket of admission to the industry.

System-specific technology refers to the information possessed by a firm or individuals within a firm that differentiates each firm from its rivals, and gives a firm its competitive edge. Some of this specific information will have been acquired through engaging in certain tasks or projects. It comprises ingenious procedures connected with a particular system, solutions to unique problems or requirements, and experiences unlike those encountered with other systems. System-specific technology is when a firm, in manufacturing an item, acquires information that is peculiar to that item. Were any other firm to manufacture that item, it too would probably obtain the same technology.

Firm-specific knowledge differs from system-specific knowledge in that it cannot be attributed to any specific item the firm produces. Firm-specific knowledge results from the firm's overall activities. Some organizations possess technical knowledge that goes beyond the general information possessed by the industry as a whole; another firm manufacturing the same products would not necessarily acquire this same technology. For example, a firm may have special capabilities in thinwall casting or metallurgical techniques not possessed by other firms, and not necessarily attributable to any specific item the firm has produced.

To illustrate the differences among the three types of technology, some of the information required for the manufacture of, say, the F-5 aircraft is common to all firms with an aircraft manufacturing capability; this we call general technology. The particular firm that manufactures the F-5 has acquired some specific information about this system not possessed by other firms; this is system-specific information. Certain other technology is possessed by this producer that other firms do not share, but which is not attributable to the F-5 (or other specific system); this is the producer's firm-specific knowledge.

The kind of information necessary for performing a certain task, and the form in which it is embodied, importantly influence the diffusion of technology and its costs. Diffusion and its costs in turn importantly influence the scope or integration of a firm and the barriers to entry encountered by potential new suppliers.[3]

A firm's willingness to diffuse its technology depends on the form in which the knowledge is embodied and the extent to which well-functioning markets for technical information exist. Assume that a firm's specific technology is protected by property rights, e.g., by a patent, and that perfect markets exist for property rights, for factors of production, and for the products or services for which the technology is used. Then the firm should be indifferent as to whether it sells the technology to other producers or uses it to produce goods and services. The value of the technology to the possessor should be the same in both cases. If markets are lacking or highly imperfect at the product level, however, the firm may be forced to sell the property rights in order to realize a return from them. Imperfect factor markets may mean, on the one hand, that the firm will be unable to obtain the resources needed to utilize the technology "in-house" at prices as low as its competitors', so it may find the sale of technology relatively more profitable. On the other hand, effective competition in the labor market may mean that the technology is diffused so rapidly that in the absence of recognized

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[3] The literature on technology and market structures has been more concerned with the generation of technology than with diffusion of technology. The literature is surveyed and extended in Nelson, Peck, and Kalachek [16, pp. 66–88].

intellectual property rights, the firm has no intellectual capital to sell. If markets for property rights are lacking or imperfect, it may pay the firm to use the technology within its own organization. If the technology is not invested with property rights, the firm cannot sell it, and the best option is to try to keep the information secret and use it within the firm. In short, the decision to sell technology or utilize it within the firm depends primarily on the intellectual property system and the perfection of markets for ideas, factors, and product.[4]

The ease with which a new firm can enter an industry depends on the considerations just discussed, as well as on the type of technology required to be an effective competitor. Established firms may be wholly unable to deter a new firm from obtaining the general technology it needs to enter an industry. If this information is publicly available, as in textbooks, other open literature, and skills of people in the general labor market, any new firm may be able to master the basic arts with minimum expense. However, even if general technology is not openly available to a newcomer, existing firms may not try to withhold it from a would-be new competitor. A well-established firm with many rivals may look with equanimity on having another competitor in the industry. It may be willing to render technical assistance at something like the direct costs involved in transferring the information. A firm with few competitors, however, may look darkly on the arrival of another one on the scene and be much less willing to sell technology. As with specific technology, existing firms are likely to have some control over access and this may be a competitive barrier that firms try to protect.

These considerations go far to explain why international, interfirm transfers of technology appear to be more common than intranational, interfirm transfers. Market position, tariffs, transportation costs, and marketing costs are undoubtedly more significant internationally. Also, "political" considerations are often overriding in determining which firms will be allowed in a market. Consequently, the international market for technology is undoubtedly better developed than national markets. Internationally, firms often buy and sell technology in situations

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[4] This discussion abstracts from uncertainty, although in international markets characterized by imperfect information, uncertainty is a vital determinant of the extent, nature, and cost of technology transfers. For a discussion of this see Y. Aharoni [1].

where domestically they would invest or do without rather than deal with a competitor.

These same considerations also contribute to the importance of the multinational corporation as an agent of transfer. Internationally, firms trading in a market may find it advantageous to establish local facilities whereas they would not do so domestically in a similar local market within a nation in which other production facilities existed [22, 1]. The multinational corporation is particularly well suited to technology transfer in such circumstances. If it is already exporting to the market in question, it has information about demands, competitive conditions, the political climate, and so forth. Also, because technology transfer is an intrafirm matter, the response to a decision to establish the technology locally may often be quicker and less expensive than establishing an interfirm market relationship through a multiple-firm program.

Thus, international corporate transfers of technology may involve a market transaction in which technology is bought and sold, or a single firm may be integrated in such a manner that the market transaction is replaced by intrafirm activities. Both arrangements have been substantial during the 1950's and 1960's. Although this study is limited to interfirm transfers, it is important to note that transfers within multinational corporations are of equal or greater importance.

Regardless of their attitude toward general technology, virtually all firms regard their specific technology as a valuable asset. Their attitude toward supplying information to other firms, however, may depend on whether it is firm-specific or system-specific technology that is to be transferred. If a firm views its firm-specific technology as giving it a competitive edge over its rivals, the firm may be loath to divulge it. There is less concern over system-specific technology; in fact, there is a substantial trade (particularly international) in designs, process information, and the like. Two factors seem to be at work here. System-specific technology is more likely to be protected by patents or other property rights, or by generally accepted proprietary claims, so the original possessor has more protection in using the information and trade is easier. Probably more important, the firm is likely to regard the technology as relevant only to one particular product. If another firm sets out to produce a competitive product, it will rediscover the technology. That being so, the original producer is likely to regard transfer of the technology as merely saving the new producer time and expense, rather than revealing some secret that could have been maintained. Ordinarily, then, system-specific knowledge is transferred more willingly than are other types of technology.

The important point is that one firm's willingness to transfer technology to another will partly depend on whether the technology is embodied in a form that can be sold, and upon the financial inducements. Willingness will also depend on whether the firm views the prospective recipient as a potential competitor. These factors in turn depend to a considerable degree upon the kind of knowledge required—that is, on whether it is general, firm-specific, or system-specific.

The process of transfer and its costs also depend upon the nature of the technology to be transferred and the form of its embodiment. General technology will probably be more costly to transplant than will firm-specific knowledge, and firm-specific more costly than system-specific, because the latter is often embodied in patents, designs, drawings, tooling, and other physical forms. Even when system-specific information is embodied solely in personnel, the transfer is still less difficult than in other kinds of technology, since the task is merely one of teaching lessons learned in other ways.

Firm-specific technology may be embodied both in physical form and in "know-how" resulting from interpersonal working relationships within an organization that are in some way difficult to separate from the firm as an entity. Firm-specific technology, therefore, can be costly to transfer.

The transplantation of general technology may be the most difficult and costly of all, since it requires intensive yet broad education in practices and procedures peculiar to an industry. Although these practices may be embodied in manuals and standard operating procedures, it may still necessitate costly experience to master them. Transfer of general technology blends into the process of general education for development.

All three types of technology were transferred in the co-production of aircraft by U.S. and Japanese companies. Although the Japanese did not methodically use these categories in deciding what technology to acquire, the categorization helps in understanding their decisions.

EARLY CO-PRODUCTION PROGRAMS

Japan's impressive World War II aviation industry came to a halt in 1945. The Western Allies prohibited Japanese aircraft production and research and development activities until April 9, 1952. When the ban was lifted, the Japanese had virtually no aircraft capability. Wartime bombings, earthquakes, and other disasters had destroyed much of the plant and equipment, experienced personnel were retired or working in other fields, and postwar advances in aerospace technology left Japan's skills and equipment largely obsolete.

The rebirth of the industry can be roughly divided into three periods. The first period began with the lifting of the ban in 1952 and lasted until about 1954, when the F-86F and T-33A programs began. During this period, the industry concentrated on repair and overhaul work for the Japanese Air Self-Defense Force (JASDF) and the U.S. Air Force [20]. At the same time, R&D and prototype production took place for several trainers and liaison planes for the Japanese Defense Agency (JDA).

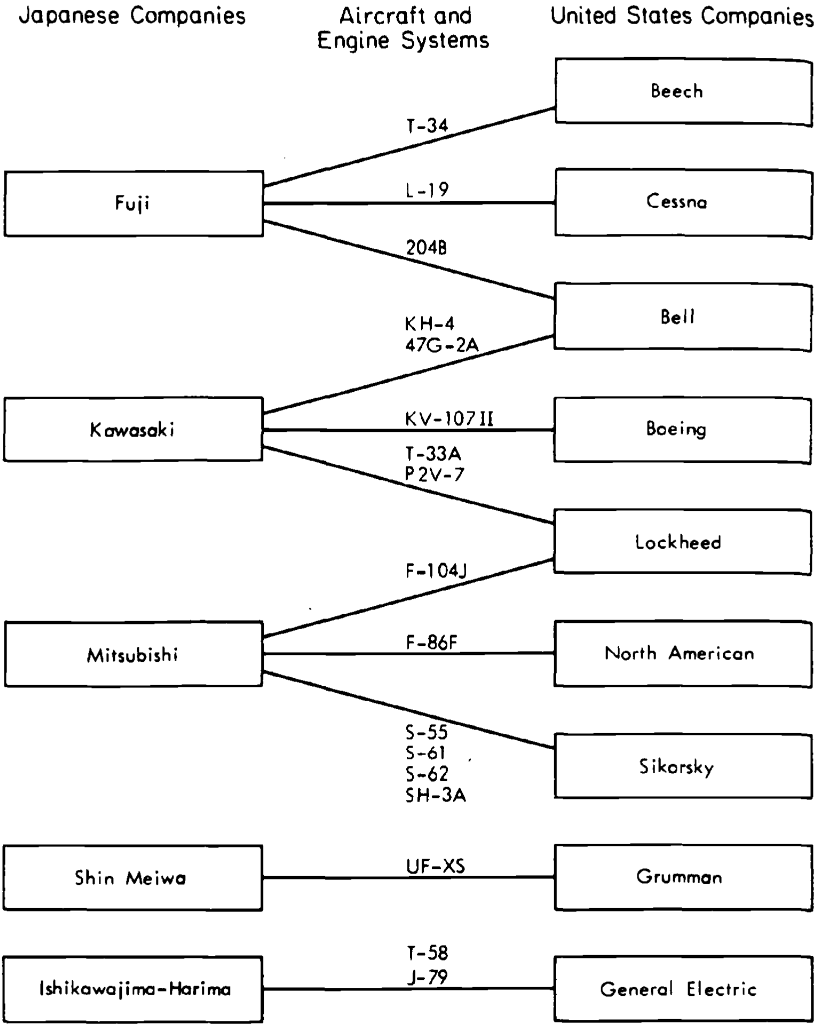
In the second period, from about 1954 to 1964, the industry added a substantial manufacturing effort to its overhaul and maintenance activities. Most of the planes produced were designed by U.S. firms, but Fuji Heavy Industries, Ltd., designed and produced two small jet trainers, and Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) developed and produced the J-3 jet engine. Several R&D programs were begun that have been important in the third period beginning in 1965. This period has also included the production of Japanese-designed commercial aircraft and several new design efforts.

Japan's aircraft industry in the mid-1960's was small, having about 20,000 employees and above $200 million in annual sales. Over 100 firms claimed membership in the industry, but 5 firms accounted for most of the output. These firms, components of major industrial groups of *zaibatsu,* all had license agreements with U.S. aerospace firms, the ties being shown in Figure 1. The middle column of Figure 1 lists U.S. aircraft and engine systems manufactured in Japan from 1954 to 1966.

Between 1952 and 1964, the Japanese industry turned out 1,422 planes with total sales prices amounting to $781.7 million ($787.7 million adjusted for price changes). Of this production, JDA took 1,117,

FIGURE 1

Co-production of U.S. Planes, Helicopters, and Engines in Japan, 1954–66



the U.S. Government 27, and domestic civilian customers 206, while 72 went for export and reparations. Manufacturing accounted for about three-fourths of the revenues earned, and repair and related activity for the rest.

Japanese aircraft manufacturing activity really began in earnest in 1957. Between 1957 and 1967, the industry turned out between 100 and 230 aircraft each year. Most were produced under U.S. license, but in later years the Japanese were increasingly involved in design projects. A short-range Japanese turboprop-airliner, the YS-11, was sold in several countries, including the United States. Plans were under discussion for production of a domestically developed interceptor and possibly a military transport.

The point is that in a very short period—largely as a result of skillful importation of technology—the Japanese acquired a small but capable and profitable aerospace industry. A key element in this accomplishment was the Japanese Government's sponsorship of military aircraft co-production programs. Co-production refers to interfirm transfers of manufacturing technology in which the developer of an item provides data, technology, and other assistance to enable another firm to manufacture the item. The first three such programs were the manufacture by Mitsubishi Heavy Industries (MHI) of the North American Aviation F-86F fighter, and the Kawasaki Aircraft Company (KAC) manufacture of the Lockheed Aircraft Corporation's (LAC) T-33A trainer and P2V-7 antisubmarine aircraft. These programs established the industry and facilitated the later manufacture of the more sophisticated Lockheed F-104J interceptor.

This study focuses on the costs of transferring the F-104J technology from the United States to Japan, a program representative of many corporate transfers of technology between countries with developed industrial capabilities. To set the stage for this discussion, however, a brief summary of the earlier programs is in order.

The transplantation of general information about U.S. aerospace practices, firm-specific information about Lockheed and North American, and even some system-specific information about the T-33A and F-86F, had begun even before co-production was instituted. Japanese firms, including those later involved in the production progress, had contracts with the USAF for aircraft work; Mitsubishi, for example, had a contract for an inspection-and-repair-as-necessary program for F-86 aircraft. This involved some importation of technology; for example, North American Aviation set up a small technical assistance program to support MHI. Mitsubishi officials state that both the direct experience with the

F-86 system and the general familiarity the firm gained with NAA procedures and systems were helpful when the F-86F co-production program began.

Co-production increased the rate, amount, and kinds of technical information provided the Japanese by several orders of magnitude. Both North American and Lockheed provided their co-production partners with extensive packages of data about corporate policies and practices, and there were many more contacts between American and Japanese personnel. For the F-86F program, for example, a group of MHI officials spent several months during 1956 at North American's facilities learning about NAA's operations. The data packages furnished contained detailed information about managerial, drafting, and other corporate procedures. (Much of this information was embodied in manuals and statements of standard procedures.)

It is easily seen that abundant general and firm-specific information was made available; it is difficult to determine exactly how much the Japanese used and how valuable they found it. But discussions with the U.S. and Japanese officials connected with the programs indicate that the Japanese airframe manufacturers adopted a considerable body of U.S. general aerospace technology and Lockheed and North American firm-specific technology. It is clear that adoption was neither slavish nor automatic. The Japanese innovated and adapted many of the basic procedures they adopted [6, pp. 80–89].

On the vendor and subcontractor level, the transplantation of general and firm-specific technology sometimes resembled that between prime contractors, and sometimes did not. The experience of some firms paralleled that of MHI and KAC; others apparently possessed all the general and firm-specific information they were interested in, and consequently desired access only to system-specific technology. For example, it appears that for generators and other electrical systems little technology except system-specific flowed to Japan.

The transfer of system-specific information about the T-33A, F-86F, and P2V-7 is easier to analyze. In general, the Japanese received all product designs and specifications and all process specifications. In particular, they had the benefit in every case either of the tooling or of the tool design information used by the developer in his production activities. They also received a great deal of planning information.

And since important data exist in the notes and black books of foremen and other production line personnel, these too were collected and made a part of the data package.

The blueprints, design drawings, and similar data transferred had to be adapted because of differences between manufacturing practices in the two countries. First, they had to be "upgraded," that is, made more detailed, because U.S. toolmakers and machinists are expected to surmise more than are their European and Japanese counterparts.[5] Second, the data and drawings in the early programs had to be translated into Japanese and into the metric system. During the peak year (1956) of the F-86 program, for example, there was a design group at MHI of about sixty people. They devoted about 70 per cent of their effort to translating drawings and specifications into the Japanese language and converting them into the metric system. From this experience MHI was subsequently able to use the Lockheed drawings for the F-104J program without translation.

Access to technical information was not a problem. When discussing data transfers, U.S. aerospace officials were emphatic in saying that their co-production partners could have access to any document. One U.S. executive flatly stated, "We were paid to put them in business, and we gave them everything we had." Nor does the story change when talking to Japanese executives. When asked if they would have liked fuller information from their U.S. co-production partners, the Japanese invariably replied that they had no problem getting blueprints and other documents.

But what about the kind of information not found in documents? This "know-how" is usually assumed to be a part of the experience of men and organizations rather than written records. One pertinent measure

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[5] This requirement illustrates the general problem of adapting technology to international differences in labor skills, training, and practices. The U.S. machinist is expected to take more independent responsibility than is his counterpart in other countries. The revision of U.S. drawings to make them compatible with Japanese shop practices required a considerable fraction of the U.S. technical assistance efforts. Another example of necessary adaptation of U.S. practices to Japanese procedures occurred in quality control. To give their decisions the ring of authority, and to save face among workers whom they implicitly "criticized," Japanese inspectors had to be given a higher rank in the corporate organization than their U.S. counterparts enjoyed. See Hall and Johnson [6, p. 82]. The point is obvious but vital. Sophisticated technology can seldom be transplanted without adaptation to local practices and skill levels. The costs of such adaptation are often significant.

of the extent to which the relevant aerospace manufacturing technology was embodied in people is the technical assistance that was furnished licensees.

For the T-33A program, LAC sent 59 advisors to Japan. Because few of them stayed the full three years, the total number of man-years spent by LAC was considerably less than 177. The team included 5 administrators, 1 manager, 1 "leg man," 1 training specialist, 1 personnel man, 8 to 10 tooling specialists (who were in Japan for only one year), 10 to 15 manufacturing planners, 2 material procurement specialists, and production specialists or others with production experience. Lockheed hired some members of the group specifically for the program. The tooling supervisor, however, was a long-time LAC employee, and Lockheed considered it important for the transfer of technology and learning to find tooling specialists familiar with Lockheed procedures.

The P2V-7 program also used a team of about 60 technical men and about the same number of man-years as the T-33 program. The contract called for 1,462 man-months of overseas technical assistance; it also provided 775 man-months of technical assistance in the United States, and an allowance of up to 78 man-months for short-term and emergency specialists.

The NAA technical assistance program was much smaller than the LAC programs. No more than 29 employees were in Japan at a time. Fewer man-months of effort were expended on F-86F technical assistance; less than 400 man-months were expended on the entire program. Of the 32 people who worked on the F-86F, all had had similar responsibilities on other F-86 programs.

The technical assistance teams were coupled to the Japanese licensees in different ways by LAC and NAA. Lockheed used what it calls the "counterpart system." Each man who went to Japan was assigned a "counterpart" Kawasaki employee at the supervisor level, and an interpreter. This system meant that a group of three worked together, and each KAC employee was able to go up the chain of command until he reached a supervisor with an American counterpart, from whom he was able to obtain assistance or advice. LAC argues that the best way to succeed in a co-production program is to participate directly in the problems of the partner. Indeed, LAC emphasizes that a large, integrated team is the key to co-production success.

North American did not integrate its team with the MHI organization nor get directly involved in MHI's activities; instead the team made itself available for advice upon request. NAA believes that its system created less friction with MHI, a firm proud of its capabilities and achievements. The NAA system also required a smaller technical assistance team.

Both methods succeeded, but LAC believes that its procedures led to better airplanes and better success in meeting schedules. NAA and MHI both hold that schedules and quality were not serious problems for the F-86F program and that some of the T-33A assistance provided by LAC was redundant.

These differences in judgment may be due to the fact that the NAA and LAC technical assistance efforts transferred different kinds of technology. The NAA team was composed of NAA employees of long standing, most of whom had had extensive experience with the manufacture of the F-86F. LAC, by contrast, hired some people with aerospace experience but who had not necessarily worked for Lockheed or worked with the T-33 before they went to Japan. This evidence indicates that NAA viewed the technical assistance requirements as the transfer of the technology specific to the F-86F, but that LAC was concerned with transfers of other types of technology as well, a fact which may explain the difference in the sizes of the teams. The implication is that system-specific technology is more susceptible to transfer in written form. General and firm-specific technology, it appears, require a process of education and occupational training with more personal interaction.

The relative importance attached to general and firm-specific technology as opposed to system-specific technology may be related to differences between MHI and KAC. When co-production began in Japan, MHI was technically a more sophisticated firm than KAC. Thus the difference in the sizes of the LAC and NAA teams may also be partly explained by the difference in the technological base of the two licensees: the larger the base, the less the general and firm-specific technology required. It is extremely difficult to analyze this hypothesis, however, because of personal considerations that confuse the data.

KAC appears to have been more willing than MHI to enter into close working relationships with U.S. firms. The F-104J program, on which Lockheed worked with MHI, should provide some basis for comparison, since Lockheed is the only American company to have worked with both MHI and KAC. Unfortunately, that information is ambiguous. MHI felt that LAC preferred Kawasaki as the prime contractor. Suspicions and doubts between the two may have led to the more formal relationship for the F-104J program than had existed between LAC and KAC on the T-33A and P2V-7 program. The F-104J program, then, cannot readily be compared with these earlier co-production efforts.

Although the amount of general and firm-specific technology transferred depends on the technology base of the licensee, it also depends on the sophistication of the system to be developed. Much of the technical assistance in the T-33A program was devoted to the transfer of general and firm-specific knowledge. The relatively large technical assistance effort required for the P2V-7, however, according to LAC sources, was due to KAC's need for the system-specific technology required for producing a more complex aircraft.

The time pattern of transfer

All programs had the same general schedule. One or more planes of each model were manufactured and test-flown in the United States, then shipped to Japan. These were followed by other U.S.-manufactured aircraft shipped in progressively less assembled form. These "knockdown" aircraft were assembled by the licensee, who thereby gained experience in assembly operations. At some point in the program, when the licensee's own assembly tools were completely operable, knockdowns were replaced by shipments of component parts. As production tooling was completed, Japanese-manufactured parts entered assembly. Another major milestone was Japanese assumption of full manufacturing responsibility, with U.S. material support primarily limited to "hardcore" items. Although the U.S. licensor supplied some parts throughout the entire manufacturing stage, these decreased in number and importance as time went on.

The contribution of this phase-in procedure to the success of the co-production programs can hardly be overemphasized. It permitted the Japanese firm to meet relatively tight production schedules while learning from the licensor.

Tooling

The provision of tooling may be the most important part of the transfer process, insofar as the transfer of learning is concerned. It can be argued that a considerable degree of production efficiency is embodied in the design of the jigs and fixtures used by production personnel, because tooling design determines the basic physical relationships between men and machines. In all co-production programs, either tool design information or the actual tooling was transferred. Although there is no way for us to judge the relative importance of these two transfers, provision of one or the other is the primary factor in the transfer of the developer's manufacturing experience to a new company.

There was considerable diversity among the programs. For the F-86F program NAA provided Mitsubishi with a complete set of tooling from its plant in Columbus, Ohio, which was being phased out of F-86 production. MHI had to refurbish some of the equipment, but in general there was far less toolmaking than starting from scratch would have required. It is impossible to quantify this statement, since MHI was building up its labor force and many people designated for production were assigned to tool building to keep them busy.

In contrast to the MHI F-86F program, KAC received only the master tools required to control interchangeability for the T-33A.[6] KAC received copies and plans necessary to reproduce all of the approximately two thousand other tools required.

Methods used for both the previous programs were used for the P2V-7 program. KAC made some tools; it also bought twenty-seven international master tooling gauges from LAC to control mating. KAC was also given two large shipments of production tooling owned by the U.S. government and no longer needed by LAC. Naturally, this reduced KAC's toolmaking expense considerably.

The special tooling required for each program was extensive, involving thousands of items. Some items were manufactured in the United States,

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[6] Master tools or gauges are used to locate specific points on the airframe for maintaining or checking accuracy.

but most were produced in Japan from designs, models, samples, and so forth, provided by the U.S. licensor.[7]

Parts and manufacturing support

The provision of parts and material support required two activities, interrelated and yet separate parts of the licensors' contractual obligations: (1) the provision of knockdown aircraft, component parts, hardcore parts, and raw materials from the United States, and (2) technical assistance in developing Japanese sources of supply.

The provision of knockdown assemblies and component parts has already been discussed as part of the interaction between phase-in and scheduling activities of production. Supply arrangements for items not produced by the U.S. co-production partner varied in each of the three programs. Lockheed dealt directly with its subcontractors for KAC. MHI procured items for the F-86F program directly from the NAA subcontractors, but NAA purchased a number of items for MHI that had been furnished by the U.S. government for the production of the F-86F.

Hardcore items—the components, parts, and materials imported from the United States—were defined by the P2V-7 contract as those items "beyond the capability of the Japanese industry to produce or . . . economically unfeasible for production in Japan." Both U.S. and Japanese sources emphasized the effort made to minimize hardcore items. The Japanese government was prepared to pay a premium to initiate domestic production. The U.S. firms assisted the implementation of this policy by accepting most of the items selected by the Japanese for the hardcore list. Many items that were furnished as hardcore in the early programs were produced domestically in later ones, since each program increased the Japanese aircraft industry's capability.

The provision of tools, assemblies, parts, and materials by the United States served a number of ends. It assured international interchangeability of certain items. It decreased Japanese production costs by

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[7] Much of the technology—and many of the improvements in technology as a result of "learning" phenomena—are embodied in tool design and changes to tooling for sophisticated products. Therefore, the role of tooling in technical assistance programs and material support deserves close attention. For more discussion of the tooling and tool designs furnished the Japanese, see Hall and Johnson [6, pp. 94–96, 107–08].

furnishing tooling the firms would otherwise have had to build and by permitting importation of parts that would have been expensive to produce in Japan. As a result, Japan had to invest only a little less than $17 million in facilities. Supply by the United States also permitted tight delivery schedules for planes to JDA. Most important, manufacturing support permitted the transfer of technology at reasonable cost.[8]

A general observation

Some quantitative features of the three early programs are summarized in Table 2. It is harder to summarize the results of the programs. Japan obtained 552 planes for its military forces which it could have purchased from NAA and LAC assembly lines, but we do not know the relative costs of importation and domestic production at that time. There were some identifiable direct spillovers as, for example, the landing gear on the commercial airliner, the YS-11, which is an adaptation of the P2V-7 landing gear. Yet, in general, these benefits are small compared with the basic outcome of the early programs: the acquisition of sufficient general and firm-specific technology to qualify Japan as a producer of advanced commercial and military aircraft.

THE F-104J PROGRAM

The three programs previously described above exemplify technology transfer from an industry with an established capability to an industry trying to establish a new capability.[9] Mitsubishi's production of the F-104J illustrates another type of transfer—between two countries with established industries.

Description of the program

On November 7, 1959, Mitsubishi Heavy Industries was notified that it would be the prime contractor for Japanese production of the

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[8] The relationship between extent of domestic production and cost has been instructively developed by Baranson in [3] and in an International Bank for Reconstruction and Development report [12].

[9] Although Japan did not have an established aircraft industry, it did have a substantial and well-developed industrial base. Thus, the early aircraft programs differ from technology transfers to less-developed countries in which more general technology must be transferred to make a co-production program successful.

TABLE 2

Japanese Co-production of U.S. Military Aircraft, 1955–63

	Type of Aircraft		
Program Feature	T-33A	P2V-7	F-86F
Total number of aircraft involved:	210	42	300
Knockdowns from U.S.	20	6	10
Component parts from U.S.	10	8	60
Fabricated in Japan	180	28	230
Items supplied from U.S.:			
Data	limited rights and all data	limited rights and all data	limited rights and all data
Technical assistance	59 men	about 60 men	32 men
Tooling	13 key masters from U.S.; about 21,000 built in Japan from U.S. designs	27 key masters some production tools from U.S.; rest built in Japan from U.S. designs	complete set from U.S.
Manufacturing support	selected parts, engines, armament	selected parts, engines, armament, some electronics	selected parts, engines, armament
Companies involved:			
U.S.	Lockheed	Lockheed	No. Amer.
Japanese	Kawasaki	Kawasaki	Mitsubishi
Period of production	1955–59	1958–63	1955–61

Lockheed F-104 Starfighter, with Kawasaki Aircraft Company as a major airframe subcontractor.[10] In the intervening period between notification and contract effective date, a two-nation agreement was negotiated, the U.S. financial contribution was determined, a license was signed between MHI and Lockheed, and several purchase agreements and contracts were made between the companies concerned. The contract between Mitsubishi and the Japanese Defense Agency, signed March 31, 1961, initiated the C-1 program for the production of 180 F-104Js and 20 trainer planes, called the F-104DJ. This program ended March 1965; it was followed early in 1966 by the C-2 program for 30 additional aircraft.

The total C-1 program cost about $269 million, of which the U.S. government contributed $75 million. It involved the Japanese manufacture of most of the airframe and J-79 engine components, plus assembly of some of the electronic items. Three F-104J planes were manufactured, assembled, and test-flown in the United States; 17 knockdowns and sets of component parts were manufactured in the United States and assembled in Japan; 160 F-104J planes were manufactured and assembled in Japan; and 20 F-104DJ planes were manufactured in the United States and should be assembled in Japan. The 30-plane C-2 program increased the proportion of engine components manufactured in Japan and added additional Japanese responsibilities for assembly and manufacture of electronics.

Data and technical assistance

The involvement of U.S. firms can be usefully divided into data, technical assistance, and material support. In the data category the most important information transferred to Japan was probably tool designs. Most tooling was built in Japan from Lockheed designs. The Japanese imported the master tools from the United States in some cases; in others, they imported plaster copies from which they made their own master tools. They also purchased tooling for tricky designs or parts hard to produce from blueprints alone.

The LAC-MHI license agreement specified a technical assistance

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[10] About 70 per cent of the airframe by weight was manufactured by Mitsubishi and about 30 per cent of Kawasaki. In dollars, the percentages were 80 and 20, Horikoshi [10].

program of approximately 1,400 man-months in Japan, paid for by the U.S. government. The major subcontractor, Kawasaki, also received LAC technical assistance. The third technical assistance effort of any size was between General Electric Company and Ishikawajima-Harima Heavy Industries Company, Ltd. (IHI) for the production of the J-79 engine. General Electric provided thirteen engineers, or about 131 man-months, at a total cost of $285,000. Other licensors of parts and components also provided some technical assistance to licensees.

Much of the technical assistance involved design changes that distinguished the F-104J from the basic F-104. Because the Japanese wanted a heavier airframe and better electronics, more manufacturing technology was required than in the earlier programs.

Unlike its experience with Kawasaki, which actively sought technical assistance, Lockheed found the Mitsubishi organization much more formal. Assistance was requested, but there was not as close a relationship between the two firms as there had been between LAC and KAC. Indeed, Mitsubishi officials expressed skepticism about the need for such a large Lockheed technical assistance team. Since the technical assistance was paid out of the U.S. contribution, however, MHI was not inclined to protest the size of the effort.

Material support—airframes

The hardcore list for the F-104J reflects Japan's interest in increasing the capability of her aircraft industry. Subject to total budgetary restrictions, everything was built in Japan that could be [10, p. 3].

The budget constraint meant that relative U.S. and Japanese production costs influenced the decision as to what technology to acquire. This fact in turn made the size of the program and rate of production important determinants of the hardcore list. As an illustration of this point, the consortium producing the European F-104G, although it had a larger budget, bought fewer hardcore items and curtailed importation of many items from the United States earlier in their program than did the Japanese because the European program was larger and the rate of production higher than in Japan [11, p. 1194].

Japan already possessed most of the required technology and facilities. In the opinion of J. Horikoshi, an MHI official during the F-104J program, the important technological capabilities acquired by the Japanese were limited to chemical milling techniques,[11] the spray-mat process to control icing,[12] and the improved capability to form and handle high-heat-treatment (4340) steel [10, p. 7].

The general qualifications of the Japanese firms are indicated by the composition of the hardcore lists. The initial hardcore list contained 226 items. By mid-1965 this number had fallen to 181. Further, 22 items originally procured as finished parts were being shipped to Japan as rough castings and forgings at this time. The 181 items on the final hardcore list were determined by the three criteria that LAC and MHI used at their conferences: (1) Capital equipment expense; (2) Project tooling expense; (3) Technical capability. As shown in Table 3, no item was classified hardcore solely from lack of technical capability; and in fact, for only 10 of the 181 items was this lack among the determining factors.

The price breakdown of Table 3, though crude, is revealing. The total cost of hardcore per aircraft was approximately $38,000. The items

TABLE 3

Items (Hardcore) Acquired From Outside Japan for F-104J Program
(classified by price and reason for acquisition)

Reason for Acquisition	No. of Line Items	Unit Price in dollars 0–100	101–500	501–1000	Over 1000
High capital equipment expense (1)	25	19	3	2	1
High project tooling expense (2)	70	42	20	7	1
Technical capability limitations (3)	0	0	0	0	0
Combination of 1 and 2	76	27	47	2	0
Combination of 1 and 3	0	0	0	0	0
Combination of 2 and 3	3	0	0	3	0
Combination of 1, 2, and 3	7	0	2	4	1
Total	181	88	72	18	3

Source: Lockheed Aircraft Corporation.

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[11] Produced under a Turco Products, Inc., license.
[12] Produced under an English Electric Company (NAPIER) license.

Lockheed supplied to Mitsubishi were primarily inexpensive; about half the total hardcore amount is accounted for by items costing from $100 to $500.

A hardcore list can be extensive for either of two mutually exclusive reasons: an item may be so sophisticated and complex that its manufacture would be difficult and expensive to transfer to another firm; or an item may be so simple and widespread in application as to be uneconomical to produce except in large quantities. In the first case, the high costs of transfer could place the item on the hardcore list. In the second case, transfer, although probably inexpensive, might be unattractive because of the economies of scale. The F-104J hardcore list reflects economies of scale more than high costs of transfer. The relatively few expensive items on the F-104J hardcore list include the air intake duct inner skins, radomes, wing skins, fuselage main frames, fuselage keelsons, empennage beams, and fuselage longerons. Inexpensive items included because of the economies of scale were mostly small pieces of hardware such as blind rivets and hi-lock bolts.

In contrast to the airframe part of the program, most of the expensive electronics items were imported. As will be discussed later, these items seem to have fallen into the category of high transfer costs rather than the second, or economies-of-scale, case.

The extent of technology transfer

The material support from the United States raises the question of how much of the F-104J was really Japanese-produced, or conversely, how much was merely Japanese assembly of U.S. manufactured items. To answer this question, data were obtained from leading Japanese participants in the program to separate vendor and subcontractor purchases from value added. The sample included five suppliers of airframe items, the engine manufacturer, and three electronics companies.

One conclusion stands out clearly. The airframe, engine, and electronics firms differed widely in their degree of domestic production.

To understand the role of these three groups, and to provide a comparison for cost figures to be presented later, Table 4 shows the average costs for sixty F-104Gs purchased in the United States in 1964 from Lockheed Aircraft Corporation. The G version is similar to the J version so it provides a good basis for cost comparisons. Note

TABLE 4

Flyaway Cost of U.S.-Produced F-104G Aircraft, Fiscal Year 1964

Item	Thousands of Dollars	Per Cent
Airframe	789	65.8
Engine	184	15.3
Electronics[a]	227	18.9
Total	1200	100.0

Source: Based on information provided by the F-104 System Program Office, USAF on a fiscal year 1964 Military Assistance Program procurement of approximately sixty aircraft.

[a] Includes estimated prices on miscellaneous items of government-furnished equipment.

that the airframe accounts for approximately two-thirds of the cost of the system, and the engine and electronics for about one-sixth each.

Table 5 presents data on the airframe part of the Japanese program. MHI, the prime contractor, produced about 80 per cent of the total value of the airframe. As the major subcontractor, KAC was responsible for the complete empennage, the forward and aft fuselage sections, and some other items.

Table 5 divides the MHI and KAC parts of the C-1 program among outside domestic purchases, imports, and the value-added by the firm.[13] About 31 per cent of MHI's purchases and about 33 per cent of KAC's were imported. Compared with the total cost of manufacture, imports were about 17 per cent for MHI and about 18 per cent for KAC. Hardcore items accounted for about 30 per cent of MHI's imports. Raw material imports were relatively insignificant. Most of the purchased items came from Japanese firms.

The value-added percentages, 45 per cent for Mitsubishi and 46 per

[13] The twenty trainers and twenty knockdowns in which MHI and KAC were only middlemen for LAC are not shown. The discussion is limited to the 160-aircraft portion of the program and its related spare parts production. The MHI figure for the KAC subcontract differs in Table 5 from the total of the KAC column because it includes the cost of KAC's assembly activity for the 20 aircraft assembly-only portion of the program.

TABLE 5

Production Experience of MHI and KAC in 160-Aircraft Portion of C-1 Program

	MHI		KAC[a]	
Item	$ Millions	Per Cent	$ Millions	Per Cent
Total imports[b]	19.95	17.1	3.52	18.0
Raw material	1.89		0.71	
Parts	12.00		2.81	
Hardcore[c]	6.06			
Total domestic purchases	44.64	38.3	7.15	36.4
Raw material	1.32		1.06	
Parts	20.48		6.09	
KAC subcontract	22.84			
Value added by firm	51.94	44.6	8.95	45.6
Total	116.53	100.0	19.62	100.0

[a] Excludes spare parts and the assembly work on the first 20 F-104J aircraft.

[b] Airframe experience only (excludes MHI import of $23.45 million of electronics).

[c] Purchased separately from LAC out of U.S. dollar contribution.

cent for Kawasaki, provide a check on the extent of the technology transfer. Had the value-added percentages been low, we would have suspected that the Japanese firms were merely importing U.S.-produced items and no significant transfer of technology was involved; but the MHI and KAC figures are about the same as the value-added percentages for U.S. airframe producers, implying that MHI and KAC were manufacturing rather than transshipping the F-104.

Since Mitsubishi purchased about $22 million worth of items from Japanese firms other than KAC, we must go below the prime-contractor level and examine the source of inputs for the Japanese vendors in order to obtain a picture of the relative Japanese and U.S. contributions

TABLE 6

Production Experience of the Three Largest MHI Vendors, 160-Aircraft Portion of the C-1 Program

(in per cent)

Item	Shinko Electric Co., Ltd.		Shimadzu Seisakusho Ltd.		Sumitomo Precision Products Co., Ltd.	
Imports	9.5		61.3		32.3	
Raw materials		0		0		11.8
Parts		9.5		61.3		20.5
Domestic purchases	14.4		11.9		46.3	
Raw materials		5.3		3.4		4.1
Parts		9.1		8.5		42.2
Value-added by firm	76.1		26.8		21.4	
Total	100.0		100.0		100.0	
Products	generators, voltage regulators		air conditioners, starters		landing gear	
Purchased by MHI	9.3		14.7		13.1	
U.S. licensor	Bendix Corp.		Garrett Corp.		Cleveland Pneumatic	

to the F-104J. Table 6 shows the production experience of the three MHI suppliers. These firms, Shinko, Shimadzu, and Sumitomo were not only quantitatively important suppliers, accounting for a third of Mitsubishi's purchases, but illustrate three different domestic supply conditions.[14]

Shimadzu's experience is an example of a supplier that made extensive use of imports. Over 80 per cent of its sales to MHI were accounted for by one product—the air conditioning system. Because this compact

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[14] For further information on Japanese subcontractors and suppliers, see Hall and Johnson [6, pp. 122–34].

and sophisticated system was unlike anything the firm had previously manufactured, most of the parts were imported from the U.S. licensor, the Garrett Corporation. Because of this one product, approximately 61 per cent of Shimadzu sales to MHI were foreign product imports. There appears to have been a severe barrier to the transfer of technology, perhaps resulting from the extreme difference in the technological base of the licensor and licensee, because this heavy reliance on imports is not characteristic of Shimadzu. Under another Garrett license, Shimadzu manufactured an electric actuator. Imports for this simpler item, of which Shimadzu was an experienced manufacturer, accounted for only 17 per cent of total sales.

Sumitomo Precision presents an intermediate case of reliance on imports. It manufactured landing gear components under a license with Cleveland Pneumatic, with imports accounting for about one-third of the total sales to MHI. At the time of the C-1 program, the Japanese industry lacked a capability for forging hard steel (especially forgings that required large-capacity double-action presses).[15] Many of the imported items required hard-steel forgings with only modest amounts of machining. The relatively heavy reliance on domestic purchases reflects primarily the involvement of Daikin Kogyo Company, Ltd., one other firm producing landing gear components.

The experience of Shinko Electric illustrates the third position on imports. Note the very low reliance on imports, even though the products are somewhat complex (voltage regulators, generators, etc.), manufactured to Bendix Corporation designs. Shinko officials state they had almost no difficulty in manufacturing the items they supplied. The reason for importing parts from the United States was primarily comparative manufacturing costs; the imports were not necessarily the most sophisticated parts, and there had been practically no technical interaction between licensor and licensee.

In short, most of the F-104J airframe was manufactured in Japan, and U.S. imports of finished items accounted for a small part of the airframe value. There was a very gradual and, on the whole, modest decline in the reliance on imports during the C-1 program; and for the C-2

[15] Japan was also limited in five-axis milling, precipitation hardening, phosphate finishing, and nitriding.

program (for thirty follow-on craft), very little import substitution was programmed for MHI, KAC, and the three leading MHI vendors.

Differences among the MHI vendors in their reliance upon imports were substantial and reflect the differences in the requirements for a successful transplantation of technology. When only system-specific information is required, transfer is easy and inexpensive even if the item is complex and the technology sophisticated. Transfer appears more difficult for items substantially different from a firm's current product, with licensees likely to rely heavily on imports of finished items from their licensors.

Material support—engines

In sharp contrast to the modest decline in imports for the airframe portion of the F-104J, the role of imports in engine co-production changed dramatically. The first twenty-nine "Japanese" engines (procured by the Japan Defense Agency from the prime contractor) were actually supplied from the United States as partly assembled knockdowns. By the end of the C-1 program, imports accounted for less than one-third of the total invoice price. IHI was the prime contractor for the J-79/GE-11A engine, with both KAC and MHI as subcontractors. Table 7 indicates the average cost experience for the C-1 program, and the IHI estimates for the follow-on C-2 program. Note the difference between the C-1 and the C-2 programs in the reliance on imports. Over half the price of an engine can be attributed to U.S. imports in the C-1 program, while in the C-2 program imports were programmed to be less than one-quarter of the price of the completed engine.

The list of C-2 program imports from General Electric Co. contained only a handful of components having unit costs of $500 or more—a small fraction of the number of such components imported for the C-1 program. A few major components were supplied by U.S. vendors, but the bulk of the imports were "nuts and bolts," in the words of one IHI official.

Compare the IHI figures with those in Table 5 for MHI and KAC. IHI had a programmed value-added of about 44.2 per cent for the C-2 phase, or about the same as that of MHI and KAC for the C-1 program. But note that in the C-1 program IHI "in-house" work accounted for

TABLE 7

IHI Production Experience of J-79 Engines: 160-Aircraft Portion of the C-1 Program and C-2 Program Estimates

	Program			
	C-1		C-2	
Items as per cent				
Imports	51.3		24.5	
Total domestic purchases	13.2		31.3	
MHI subcontract		6.1		9.4
KAC subcontract		1.7		2.5
Other		5.4		19.4
Value added by IHI	35.5		44.2	
Total	100.0		100.0	
Program size in $ millions[a]	44.39		7.14	

[a] Contract information supplied by JDA

only about 35.5 per cent of the total engine price. Domestic purchases differ even more. For the C-1 program only 13.2 per cent of the engine price was spent on IHI purchases from Japanese firms; comparable figures for MHI and KAC were 38.3 and 36.4 per cent. IHI's domestic purchases were programmed for about 31.3 per cent for the C-2 program. In other words, IHI's sources of supply for the C-2 program were about the same as MHI's and KAC's were for the C-1 program. This means that Japan's engine self-sufficiency lagged behind its airframe self-sufficiency by about five years.

Material support—electronics

Most F-104J electronics were not co-produced in the same sense that the airframe and engine were co-produced. The twenty F-104DJ aircraft and the first twenty F-104J aircraft were completely equipped with electronics from U.S. suppliers. For the remaining 160 F-104J aircraft in the C-1 program, 160 sets of major items of electronics were imported.

To learn more about the Japanese role in providing spare electronics

TABLE 8

Selected JDA Expenditures on Electronics: C-1 Program

			Imports		Value Added in Japan		Total Imports and Value Added	
Item	Quantity	Supplier	$ Mil.	Per Cent	$ Mil.	Per Cent	$ Mil.	Per Cent
NASARR	27	Mitsubishi Electric	3.2		0.9		4.1	
Stable platform	24	Mitsubishi Precision	0.9		0.4		1.3	
Air data computer	24	Shimadzu Seisakusho	0.6		0.2		0.8	
Total			4.7	75.8	1.5	24.2	6.2	100.0

units, data were assembled on the North American Search and Range Radar (NASARR) fire control system procured from Mitsubishi Electric, the stable platform procured from Mitsubishi Precision, and the air data computer procured from Shimadzu. These three items accounted for about three-fourths of the total cost of the electronics items. (See Table 8.) Imports accounted for over 75 per cent of the total sales price. Discussions with the Japanese corporate officials confirmed that the Japanese firms had only assembled and tested imported parts.

The relative costs of imports and domestically assembled components for the electronics part of the F-104J program were high. The average unit cost of the completed items imported is about 20 per cent lower than the cost of the parts for the components assembled in Japan. Table 9 compares the average prices paid by the Japanese government for the components assembled in Japan with the unit costs of complete components imported from the United States. Subtracting the value-added in Japan from the unit cost gives the cost of the imported parts used in assembly. The costs of these parts are uniformly higher than the costs of the completely assembled components imported.

The implication of these data is that the Japanese electronics assembly part of the program was subsidized by the Japanese government to enable Japanese manufacturers to gain familiarity with the more sophisticated electronic products.

TABLE 9

Average Unit Costs of Selected Items of Electronics
(thousands of dollars)

				Spare Units Assembled in Japan		
Item	U.S. Unit Cost	Quantity	U.S.-Supplied Imported Parts Used in Assembly	Value-Added in Japan	Total Unit Cost, Japan	Quantity
NASARR	95.5	160	119.4	33.1	152.5	27
Stable platform	31.5	160	36.8	16.5	53.3	24
Air data computer	23.2	160	26.5	8.1	34.6	24

Summary of material support data

Some key features of the F-104J program are shown in Table 10. A major share of the fabrication of the F-104J took place in Japan, but the transplantation of U.S. technology varied considerably among different parts of the program. Most of the airframe was produced in Japan after the first twenty aircraft were assembled. By 1966 most of the engine was produced in Japan, but it took the entire C-1 program for the necessary technology to be transferred completely. Very little of the electronics technology was transferred.[16]

Through previous overhaul and airframe co-production programs, Japanese airframe manufacturers had acquired substantial command over most of the general airframe manufacturing technology. Since very little general technology was required, the transplantation was rapidly accomplished. The airframe situation also appears characteristic of various component suppliers such as Shinko Electric, the generator producer.

The electronics situation contrasts sharply with the airframe experi-

TABLE 10

Japanese Co-Production of the F-104J, 1961–67 –Lockheed-Mitsubishi

Total number of aircraft involved:	207
Knockdowns from U.S.	7
Component parts from U.S.	10
Fabricated in Japan	190
Items supplied from U.S.:	
Data	limited rights and all data
Technical assistance	about 60 men
Tooling	11 key masters and over 5,000 plaster splashes and Mylar reproductions. Tooling built in Japan from U.S. designs.
Manufacturing support	selected parts, some engines, armament, most electronics.

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[16] In dollar terms, the airframe accounted for about 60 per cent of the cost of the aircraft, and the other two categories for about 20 per cent each.

ence. Japan's reputation in the field of commercial electronics might lead one to expect that the F-104J electronics gear would be manufactured in Japan without difficulty. In fact, however, little electronics manufacture took place on the C-1 program. Most major electronics items were imported from the United States.

The explanation given by Japanese executives is that there are substantial differences between sophisticated military electronics and the commercial field in which Japanese firms are experienced—in physical characteristics and in specifications. This indicates that production of items such as the NASARR or the stable platform would have required the transfer of general technology associated with the military electronics field rather than merely the specific technology associated with the particular systems.

Through assembly and spare parts manufacturing, the Japanese generally have been acquiring the general technology of military electronics. Future aircraft programs should show a pattern in electronics more like that in the airframe portion of the F-104J program.

The J-79 engine experience tends to support this prediction. Unlike electronics, the Japanese had had some experience in jet engine production at the outset of the C-1 program; by the end of the C-1 program the engine was produced almost entirely in Japan. The transfer process for engine technology took much longer than did the airframe, probably because the Japanese had had extensive prior experience in airframe production, which gave them a relatively large stock of general manufacturing technology.

The F-104J experience illustrates that the transfer of technology need not be an all-or-nothing matter. The ability to import parts, supplies, materials, and technical assistance permits a gradual and partial transfer of the technology required for an item. This process is well exemplified by the engine and electronics portions of the program.

The F-104J experience suggests that the ease of transferring manufacturing technology for an aircraft importantly depends upon the amount of general knowledge that must be included in the transfer. If the backgrounds of the firms are so different that the transfer of general technology is necessary, a firm is likely to limit its initial activities to assembly and repair—activities that appear to facilitate the gradual transfer of general technology.

THE ECONOMICS OF TRANSFER

Two classes of costs are incurred when technology is transferred from one firm to another. First, there are direct costs, or the financial outlays required to move the necessary technology. Second, there are indirect costs in the form of increased production costs incurred because manufacturing responsibility is divided rather than concentrated at a single point. The direct and indirect costs of the F-104J technology transfer will first be considered; then the total cost of producing the F-104J will be compared with that of another F-104 model produced in the United States.[17]

Direct costs

The major direct costs were license fees, royalties, and technical assistance payments.[18] Considering royalties and license fees first, each Japanese producer of a U.S. proprietary item had to make some financial arrangement for manufacturing and data rights. MHI paid Lockheed $1.5 million plus a royalty of about $31,500 for each of the 160 F-104Js manufactured in Japan during the C-1 program. These payments followed the pattern set in the earlier programs.

There were many additional license agreements at the vendor level, usually amounting to about 5 per cent of the invoice price of the licensee's product, with a modest initial payment or none at all. That portion of the invoice price represented by parts and materials purchased by the licensee from the licensor was ordinarily excluded from royalty payments.

[17] Only occasional reference will be made to earlier programs, since they took place before Japan had a fully developed aircraft industry.

[18] The license between Lockheed and Mitsubishi covered ten years. It provided for manufacturing rights, development activities, technical data, technical assistance, and all warranties. Only items designed by Lockheed were included in the license. LAC provided all data required for manufacture, including revisions during the license term. The assembly of the plane and all LAC-designed items were warranted, but not items of other firms' design. Mitsubishi had exclusive rights to sell the F-104J, but only to the Japanese government. MHI agreed to pay LAC $5.8 million to develop the J version of the airframe: a fixed fee of $1.5 million for the manufacturing rights and data, plus a royalty on each plane made in Japan, this to be $32,000 for the first plane, dropping to $25,000 on the 201st plane. On spare parts not purchased from LAC, MHI agreed to pay a 5 per cent royalty.

Estimated total royalties on the airframe portion of the program are shown in Table 11. Total royalties have been estimated at 5 per cent of the total work performed by Japanese vendors, or $765,000. This figure was obtained from Table 5, which shows that MHI's purchases in Japan were $21.8 million, excluding the KAC subcontract. Approximately 30 per cent of this amount in turn went to purchases from U.S. vendors. For the remaining 70 per cent ($15.3 million), we assume an average royalty payment of 5 per cent. The unit cost figures shown in

TABLE 11

Payment for Rights and Technical Assistance in the F-104J Program
(thousands of dollars)

Item	Cost
Airframe technology	Per Airframe
Technical assistance	20.8[a]
Total manufacturing rights	42.8
Initial payment to Lockheed	7.5[b]
Royalty to Lockheed	31.5[c]
Vendors' royalty to Lockheed	3.8[d]
Total	63.6
Engine technology	Per Engine
Technical assistance	1.1[e]
Total manufacturing rights	10.8
Initial payment to GE	10.0[f]
Royalty payment to GE vendors	0.8[g]
Total	11.9

[a] Technical assistance of $4.16 million/200 airframes.
[b] Payment of $1.5 million/200 airframes.
[c] Average for the first 160 airplanes.
[d] Estimated as 0.05 x 15.3 million/200 airframes.
[e] Technical assistance of $0.28 million/250 engines.
[f] Payment of $2.5 million/250 engines.
[g] Estimated as 0.05 x 4.1 million/250 engines.

Table 11 were obtained by allocating costs (except for the Lockheed royalty) to approximately two hundred airframes.[19]

For the J-79 engine, $2.5 million was paid by IHI to GE for three hundred engines on a royalty-free basis. IHI also made royalty payments to certain GE vendors. These were computed from the data in Table 7, assuming there were no royalty charges for IHI domestic purchases that were ultimately supplied by U.S. vendors. For the remainder ($4.1 million) a 5 per cent average royalty was again assumed. These charges were allocated to 250 engines, the approximate C-1 and C-2 production.

Payments for technical assistance have been allocated in the same fashion as payments for rights. Japanese vendors received minimal technical assistance from licensors. Those technical assistance programs of significant size were with MHI, KAC, and IHI.

We are now in a position to examine the direct costs of transfer in relation to total production costs.[20] For this purpose the F-104G costs shown in Table 4 will be used. According to Table 11, direct costs of airframe technology transfer amounted to $63,600 per plane or about 8.1 per cent of the total F-104G airframe cost. Direct costs for engine technology transfer were $11,900 per engine, or about 6.5 per cent of the comparable U.S.-produced engine cost. Together, these represent about 7.8 per cent of the total cost of the airframe and engine. Technical assistance amounted to more than a quarter of the total direct costs of transfer.[21]

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[19] The 200-airframe figure was obtained by adding the 160-unit C-1 program to the 30-unit C-2 program and assuming that the production of a substantial number of spares in the C-1 program was equal to ten complete airframes. The 20 F-104DJ's and the 20 F-104J's supplied in the form of knockdowns were excluded. Because there was little or no Japanese production for these parts of the C-1 program, it is inappropriate to allocate royalties, license fees, etc., to these planes.

[20] No figures are presented for the electronics part of the program, since it is not clear how much or what type of technology was transferred.

[21] The payments for technical assistance differ from the payments for licenses and rights. The former are payments for a new service—the activities required to diffuse knowledge. Licenses and royalties, on the other hand, are economic rents; they are not payments for the production of any new goods or service. Thus, the "real" economic cost of transfer of technology is less than the nominal financial costs. Present institutional arrangements, however, give firms property or quasiproperty rights in the ideas, data, and designs embodied in a finished system. Transfer requires payments to the owner of these rights in order to induce them to forego their rights not to disclose their knowledge.

Indirect costs

Production costs are influenced by the rate of learning and the economies of scale. These factors are in turn determined by the rate of production, the volume of production, and the delivery schedule. This relationship can be formally stated as

$$C = f(x, V, T, m),$$

where C denotes the cost, x the rate of output, V the scheduled volume of output, T the time output begins, and m the length of the output period. T and m fix the production period measured from the time the program begins. Note that there are only three degrees of freedom; specification of any three variables fixes the fourth.[22]

The rate of production is the central variable in the economic literature on costs, while the volume of production is the central variable in the literature on learning or progress curves. Our present concern is not with the total costs of production attributable to each variable; it is how these costs vary with the number of producers in a program, and what costs can be avoided when production responsibility is concentrated in a single firm. To this end we will discuss each variable.

The relationship between costs and the rate of production is traditionally divided into two parts: the relationship between output and investment in plant and equipment (economies of scale), and the relationship between output and variable factors of production (economies of plant utilization). Let us consider investment first. Both Lockheed and Mitsubishi had the factory space and basic equipment required for F-104 production. Few new facilities had to be added in Japan specifically for the program. About $10.1 million worth of capital investment in Japanese aircraft capability was designated for the F-104J; private investment accounted for about $8.4 million of this total. Most of this investment was for the J-79 engine. IHI invested $5.3 million and the Japanese Government an additional $1.1 million in J-79 engine facilities.

Tooling costs are more easily attributed to a specific program than are plant and facility investment expenditures. The extra tooling costs in a co-production program greatly depend on how much tooling is transferred from the original producer. Usually, this means that the

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[22] This information and much of the discussion to follow is based on the work of Alchian and Hirshleifer [2, 9, 8].

tooling expense attributable to co-production depends on the extent to which production in the new and old locations overlaps.

Precise tooling costs for the F-104J program are unavailable, but a reasonable estimate can be derived from MHI's man-hour figures. MHI invested about 1.5 million man-hours in the original tooling. (Total MHI man-hours for all portions of the C-1 program were about 7.0 million.) The MHI tooling experience appears reasonable when compared with Lockheed's original tooling for the F-104A, about 1.4 million man-hours.

Costing the Japanese tooling expenditure is difficult, but if we use the Japanese aviation industry rule of thumb, which estimates labor costs at $3 per hour, we arrive at a tooling cost of about $4.5 million, plus some allowance for overhead and indirect expenses. Added to this figure should be the tooling costs of the other firms in the program, but little relevant information on that is available. MHI did most of the airframe tooling, and it appears that the only other major tooling expenditure was for the engine, for which no data are available.

The cost for MHI's tooling is somewhat overstated because some personnel destined for work on other parts of the program were put to work building tools. This extra expense, however, is properly regarded as a setup cost that could have been avoided if Lockheed had produced the F-104Js.

In sum, as a rough and probably high estimate, we can attribute to the investment costs of the airframe portion of the C-1 program, $3.7 million for plant and facilities and $4.5 million for direct tooling labor. Dividing this total by two hundred planes yields a unit-fixed-cost of $41,000. It was noted earlier that Lockheed sold the F-104G airframe for about $789,000 per copy, and it appears likely that the Japanese could also have bought airframes from LAC for this price. We may therefore conclude that the avoidable fixed cost amounted to a little more than 5 per cent of the airframe cost.

It does not appear that the relationship between the rate of production and tooling costs should importantly affect the costs attributed to dividing production rather than concentrating it within a single firm. The tooling for the original producer would have been designed with some particular rate of production and total output in mind. Transfer of the program to another manufacturer would not affect the total quantity to be bought nor should it affect the rate of production unless the transfer required so much time that the total volume for the program could not be produced with the originally scheduled rate of production. In that case, either the length of the production period would have to be extended or the rate of production would have to be increased. Increasing the rate of production would therefore be a cost attributable to the separation.[23] The important consideration is the impact of separation on scheduling.

The usual view is that the shorter the period between the start of a program and the delivery of the first item, the greater the cost. In a domestic program with a specified volume of production and a specified rate of production, higher costs can be expected if an early target date is established for the first delivery. In international co-production programs, however, the date of first delivery will partly govern the amount and type of imports. The earlier the date of delivery, the more knockdown and component parts will be acquired from the original supplier. The cost impact will depend on the relative costs of foreign and domestic production.

The schedule may affect costs in still another way. The longer the time between the start of a program and the date of first delivery, the less hurried the process of transferring the technology can be. The direct costs and effectiveness of transfer may be related to the speed of transfer. Certainly the phase-in process, previously emphasized as a key to successful transfer of learning, is likely to be hindered by a tight schedule.

The important point is that technology transfer is not a single event, but a series of events occurring over a period of time. Considerable flexibility is possible in adjusting the transfer of programs and technology to meet delivery schedule requirements. Such adjustment, of course, requires substantial and careful planning, but skillful planning can minimize the impact of transfer on the rate of production.

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[23] The relationship between co-production and the costs associated with the rate of production depend on how the co-production program is organized. Recall the equation $C = f(x, V, T, m)$, and assume V is fixed. If T and m (the schedule) can be adjusted for the time required to transfer the program, or if no extra time is required to effect the transfer, x is not affected by co-production. If, however, transfer takes time and T and m are fixed, x will have to increase. If we make the usual assumptions about the relationship between C and x, there will be some additional indirect costs.

Turning to the indirect cost implications of the volume of production, it should be kept in mind that we are concerned with the cost associated with dividing a single program between two firms. The underlying determinants of total cost are not at issue. Consequently, our interest in the influence of production volume centers on the impact of co-production on progress or learning curves. In the consideration of progress curves, as Hirshleifer has pointed out, costs are influenced by two aspects of volume: the actual output and the scheduled total output [9, pp. 239–40]. Increasing familiarity with production processes should increase labor-force productivity and thereby progressively lower unit costs [8, pp. 146–47]. For this effect, it is the actual output that is important. An increase in the scheduled volume of output will lead to different managerial decisions about investment in facilities and tooling and to different production procedures that should also lead to progressively lower unit costs [9, p. 240]. For this latter effect the scheduled output, rather than the actual output, is significant. Here, since actual and scheduled outputs were the same, we cannot distinguish between the two situations. More generally, however, in analyzing the costs of transferring technology, it is important to specify whether actual or scheduled production is the measure.

Two interfirm comparisons of the volume-cost relationship are of interest. Assume that the first firm has a total cumulative production equal to N units. Also assume that the second firm is going to take on a co-production program of n units. One comparison is between the cost of the original producer's first n units and the second firm's costs for n units. This comparison indicates (assuming all adjustments for other cost effects such as economies of scale have been made and that the firms are equally efficient) the extent to which the first firm's learning was transferred to the second firm.[24]

The second comparison is between the cost of n units produced by the new manufacturer and the cost of units N to $N + n$, had they been manufactured by the original producer. This comparison indicates the cost impact of splitting the production run between two firms. The comparisons will be considered in order.

For the first comparison, if the two firms have identical progress

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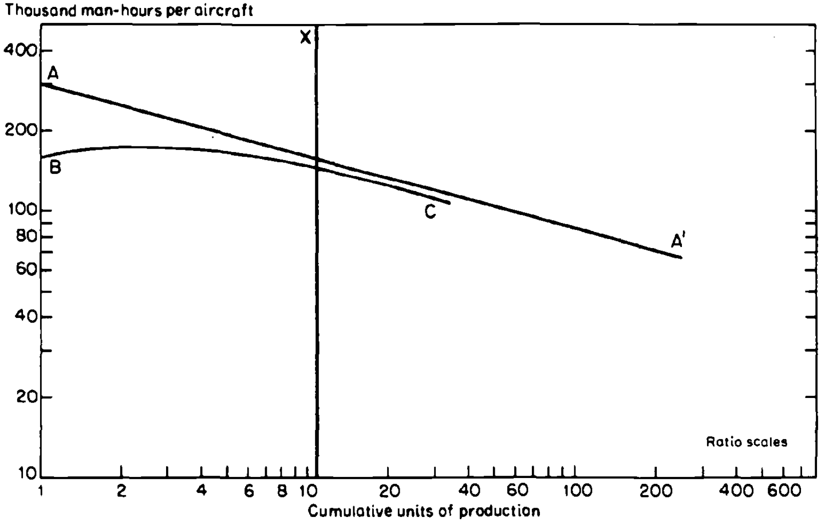
[24] L. E. Preston and E. C. Keachie discuss the relationship between learning and economies of scale [18].

curves, no learning has transferred. If the licensee's unit cost is lower for the first unit than that experienced by the first producer, or if his curve shows a steeper "slope,"[25] then some learning has been transferred. If the new firm's initial unit cost equals the licensing firm's unit cost at the time of transfer, and if the slope of the progress curves for both firms from that point on is the same, all learning has been transferred.

Figure 2 illustrates these relationships. Following the usual practice in progress curve measurement, the figure shows direct labor hours per aircraft as a function of total number of units produced. The line *A*-*A* represents the licensor's progress curve. Assume that a co-production program is established at point *X* after ten units have been produced by the licensor. If all of the licensor's learning has been transferred, the licensee's man-hour requirements for his first unit will correspond to those needed by the licensor for the eleventh unit. This 10-unit advan-

FIGURE 2

Learning Transfer Effects; Illustrative Progress Curves



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[25] "Slope" has a meaning in progress-curve analysis different from its mathematical meaning. Here it refers to the ratio $[c_t/(c_t/2)]100$ where c_t is the production cost of the *t*th unit of output.

tage would remain with the licensee throughout his production. This situation is shown by the progress curve *B-C*, which approaches the licensor's curve asymptotically. Of course, if none of the licensor's learning is transferred and interfirm differences are ignored, then the licensee's progress curve will be identical to that of the licensor.

In most programs, some but not all of the licensor's learning will be transferred. Thus, the licensee's initial position will lie somewhere between *A* and *B*. Moreover, the slopes of the two curves may or may not converge in the manner shown, depending on differences in efficiency and factor prices which have been ignored for the sake of illustration. The important point, however, is that the transfer of learning results in the new producer requiring fewer man-hours for his initial production than were required by the original producer.

Let us examine the F-104J in this manner. Early in the program, LAC officials made estimates of the direct manufacturing man-hours required by MHI and KAC. LAC officials stationed in the Japanese plants observed that these early estimates conformed reasonably well to the actual man-hour expenditures of the two firms. Although these early estimates have some speculative aspects, they provide a basis for quantitative estimates of the amount of learning actually transferred.

In order to compare the Japanese and U.S. experience, some data had to be adjusted in the following manner: we know that a number of airframe items were manufactured in the United States, and some were purchased from Japanese vendors; both these factors must be accounted for. We estimate the price of that part of the airframe produced at Lockheed, which excludes equipment-purchase items, to be about $520,000, or roughly two-thirds of the total airframe costs shown in Table 4. Imports of hardcore airframe shown in Table 5 accounted for approximately $38,000 per airframe. LAC officials estimate total imports of airframe items to be approximately $50,000 per airframe. This, plus an estimated $40,000 for airframe purchases from Japanese vendors, shows us that approximately 17 per cent of the total airframe effort was performed outside the MHI and KAC facilities. As shown in Table 12, we can now estimate the total direct man-hours as 21 per cent more than the amounts actually spent by MHI and KAC.

The Japanese data are now in a form that can be compared with Lockheed experience. Choosing the LAC base is difficult, however. Our

TABLE 12

Direct Man-Hours, Manufacturing: 160 F-104J Airframes
(in millions)

MHI	3.98[a]
KAC	1.71[a]
Other	1.19[b]
Total	6.88

[a] Estimated by officials of LAC.

[b] Estimated at 21 per cent of the total MHI and KAC man-hours. Total outside work was approximately $90,000 per unit. Exclusive of equipment purchase items, LAC airframes cost about $520,000, and 90/(520-90) = 21 per cent.

choice is the first 160 F-104As and F-104Cs. However, the F-104J airframe was at least 20 per cent heavier and in other ways differed from U.S. versions. Indeed, on a cost-per-pound basis, as progress curves are sometimes expressed, the Japanese experience would be much more impressive than on the cost-per-plane basis used here. The Lockheed production of F-104Gs or F-104J knockdowns might also be introduced, but it would be difficult to adjust the data for learning accumulated from previous models or for the assembly operations not performed. Consequently, we have preferred to use the F-104A and F-104C for the comparison even though doing so may understate the U.S. cost relative to the Japanese cost. This means that any statistical biases are in the direction of understating the interfirm transfer of learning.

LAC and MHI progress curves are shown in Table 13. For the first 10 F-104s produced by each firm, MHI used substantially fewer man-hours than did LAC. The LAC man-hour rate per plane was slightly less than the MHI rate per plane by the time each had completed 160 aircraft. Direct man-hours used for the first 160 airframes by the Japanese were only about 90 per cent of the total LAC man-hours for the first 160 F-104s built in the United States.

The relationship between the two learning curves is shown in Figure 3. The rate of learning in Japan (85 per cent slope) is well below the U.S.

TABLE 13

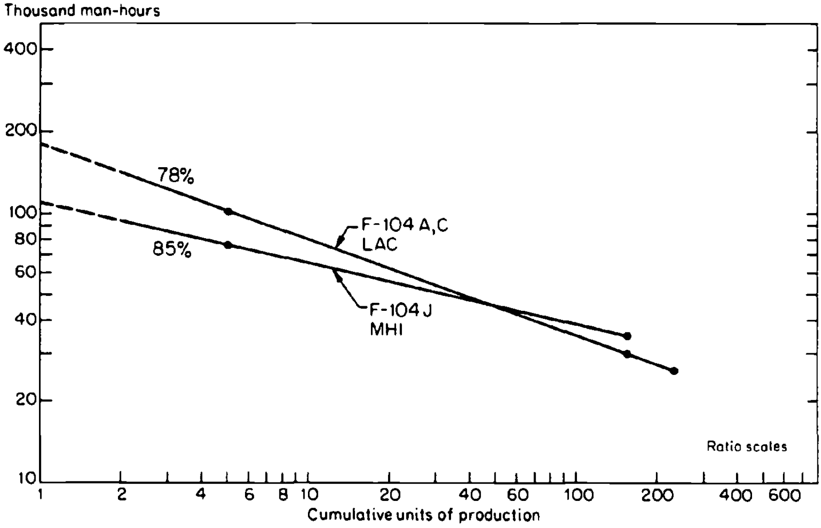
Comparison of U.S. and Japanese Direct Man-Hours, Manufacturing
(in thousands)

Numbers of Aircraft	First U.S. Program F-104A, F104C	First Japanese Program F-104J
1-10 (average)	101.0	76.4[a]
150-160 (average)	30.5	33.1[a]
1-160 (total)	7590.0	6880.0

[a] Based on Lockheed estimates of MHI direct man-hours, inflated by the ratio of total Japanese man-hours to MHI man-hours shown in Table 12 (6.88/3.98 = 1.73).

FIGURE 3

Comparative F-104 Progress Curves



rate (78 per cent slope). However, the lower cost in Japan for the first units meant that the total Japanese man-hour expenditure was lower than Lockheed's expenditure for the first 160 planes it produced. Average man-hours per plane for the first 160 produced by each firm were 43,000 for MHI and 47,400 for LAC.

We are now in a position to answer the first of our two questions: How much learning was transferred from LAC to MHI? If we assume that the firms were equally efficient and that the rate of production and delivery schedule did not affect man-hour improvement, some summary estimates can be made.

One measure would be to assume that in the absence of a transfer of learning, MHI would have had the same man-hours for the first unit as LAC had for its first unit. Actually, MHI's figure was about 25 per cent lower, or about the number of man-hours LAC used to produce the fourth plane.

On the other hand, one might take the entire 160-plane program as the basis. Since the rate of improvement for MHI was less than for LAC, this gives a lower figure, about 10 per cent. The higher estimate of the amount of learning transferred seems the more reasonable one, considering the fact that the Japanese labor system results in high factory manning levels.

Employment by a large Japanese firm implies a lifetime commitment. Therefore, one often observes more labor hours per unit of Japanese output than are technically required, or than are typically observed in the United States. Probably more important, there are large differences in wage rates between the United States and Japan. Differences by a factor of three are not uncommon in the "blue collar" aerospace skills. Capital equipment is, if anything, more expensive in Japan, so it is not surprising that the Japanese tend to use larger work forces to reduce idle equipment time. In general, because of different factor prices, we would expect the Japanese to use more labor-intensive processes than do U.S. firms. These considerations imply that more man-hours per plane would be expended in Japan than in the United States, regardless of the amount of learning transferred.

In short, it appears reasonable to conclude that a substantial amount of learning was transferred—enough so that the man-hours used on the first MHI F-104 were 25 per cent less than those required for the first

LAC F-104. For the program as a whole, the learning transferred saved MHI about 10 per cent of the man-hours required by LAC for its first 160 aircraft.

Addressing the second comparison, i.e., between the man-hours used by MHI and those that would have been required had the 160 F-104Js come off the LAC assembly line, the problem is to compare the total MHI man-hours for 160 aircraft (6.9 million) with the total LAC would have required to produce an additional 160 aircraft. Based on very limited data about the F-104G, the total output by LAC of all F-104 models at the time of transfer, and LAC's rate of learning discussed earlier (78 per cent), we estimate that total LAC man-hours for an additional 160 aircraft would have been 3.7 million, or about 23,000 man-hours per plane. On this basis it appears the MHI man-hours were nearly twice what LAC would have required.[26]

Even if Japanese production did require perhaps twice as many man-hours, total labor costs appear to have been lower. Although international comparisons with Japanese labor rates are tricky, knowledgeable Japanese officials believe that a good order of estimate might be about one-third the U.S. rates. On the basis of the total cost data for the F-104J program, this estimate appears slightly high, or else our estimate of the man-hour requirements is slightly high, or most likely, both are high. Nonetheless, the total cost figures to be discussed shortly indicate that as orders of magnitude, these estimates are credible.

Technology transfer incurs not only direct costs, such as royalties and technical assistance payments, but also the indirect costs associated with the loss of economies of scale and with learning and scheduling. The direct costs can be estimated with some precision. For the F-104J program, for example, the direct costs amounted to about 7.8 per cent of the price of the complete airframe and engine. Technical assistance accounted for about a quarter of the direct costs.

Indirect costs are harder to estimate. Splitting production between

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[26] Actually, 87 per cent greater, were such computational accuracy warranted: $[(6.9 - 3.7)/3.7] = 87$ per cent. The estimate of Lockheed man-hours is understated for two reasons. First, it assumes a constant progress-curve slope; the curve might have flattened out. More important, with each new model of the F-104 at Lockheed, the progress curve shifted upward. Undoubtedly, if the F-104J had been produced in the United States the man-hours for the first J version plane would have been higher than the end-point of Lockheed's F-104 progress curve shown for the earlier period.

two sources can affect production rates, lot sizes, and schedules. Each of these impacts affects production costs.

The production rate or economies-of-scale effects and the schedule effects importantly govern the extent of the "hardcore" lists—the components, parts, and materials imported. Extensive economies of scale or tight delivery schedules imply larger amounts of imports.

Transplantation of technology will almost always entail some loss of learning due to lower total quantities of production at any single location. This impact, however, can be lessened by the transfer of learning from the original producer to the technology recipient. In the F-104J program, it appears that between 10 per cent and 25 per cent of Lockheed's progress-curve advantage was transferred to Mitsubishi.

Total cost of production

Let us now examine the total cost of F-104Js to the Japanese government and compare it with the price Japan might have paid for finished airplanes in the United States.

It is well known that the Japanese co-production programs required more man-hours than would have been required in the United States. It is also well known that certain parts and materials produced in Japan cost more than the U.S. counterparts. Furthermore, some investment and set-up costs were incurred that could have been avoided by purchasing from a "hot" production line. As a result, it has been commonly assumed that the Japanese planes cost anywhere from 20 to 100 per cent more than they would have in the United States. The actual cost data for the F-104J program confute these common notions, however.

In fact, no premium was paid. The Japanese obtained the planes at a lower cost than they would have paid in the United States.

The high materials costs for the F-104J program appear to have been more than offset by the lower labor costs in Japan. Although it is impossible to estimate precisely the impact of the differences in factor prices, the figures in Table 13 indicate that the factor-cost saving must have been large.

Table 14 shows that in Japan for 160 aircraft the cost for an airframe was $620,000 as against a U.S. cost of $789,000 for an F-104G bought in smaller lot sizes. For the engine, the Japanese cost was higher—$232,000 compared with $184,000. Adding these two totals gives an

TABLE 14

Comparison of U.S. and Japanese Average Unit Production Costs for F-104 Aircraft

(thousands of dollars)

Item	Japanese Production (F-104J Aircraft)	U.S. Production (F-104G Aircraft)
F-104 airframe[a]	620[b]	789
J-79 engine	232[c]	184
Total	852	937

[a] Includes all items of installed equipment other than electronics.

[b] Includes payments to Lockheed for technical assistance, tools, data, and cataloging shown in Table 11, allocated to 200 airframes.

[c] Includes payments to General Electric for technical assistance shown in Table 11, allocated to 250 engines.

F-104J unit cost of $852,000—about seven-eighths the U.S. price of a comparable plane.

The Japanese costs include technical assistance ($20,800 for airframe, $1,100 per engine); rights ($42,800 per airframe, $10,800 per engine); tooling and start-up costs (direct costs were about $41,000 per airframe); and all other manufacturing costs. The unit-cost estimates are therefore slightly exaggerated, because none of these costs are allocated to the C-2 program or spare parts production. The only identifiable cost not included is the fixed investment for the program; it was omitted because LAC had some government-furnished plant and equipment, and its facilities were used on programs other than the F-104. Therefore, it was not clear what the corresponding figure for the United States should be. Even leaving the F-104J costs unadjusted, however, and allocating all fixed investment earmarked for the F-104J program, the basic conclusion remains the same. Allocating the investment would increase the airframe cost by $23,000 and the engine cost by $32,000. This total increase of $55,000 would give a total figure for the F-104J of $907,000. This is still approximately 10 per cent below the price Lockheed charged for the F-104G.

Electronics are not included in the calculation for two reasons. First, they were not co-produced in Japan during the C-1 program, certainly not in the sense that airframes and engines were co-produced. Second, the J and G versions of the F-104 differ substantially in electronics, even though the planes are essentially identical in terms of airframes and engines. Since the C-1 electronics were imported, they do not affect the cost comparison.

Differences in factor prices tend to cloud the issue. Nonetheless, quite apart from any beneficial effects to the Japanese aviation industry, it is clear that the decision to co-produce the airframe was economically advantageous for Japan.

CONCLUSIONS

This paper has considered the costs of international transfers of sophisticated technology. The reasons for desiring such a transplantation are outside the scope of this analysis, but a few comments are in order. Most interfirm transfers, at least among firms in countries with developed economies, occur because a firm perceives some profit advantage from establishing a local production capability [7]. Some transfers, of which the cases considered here are examples, occur for reasons other than simple, short-run economic gain. The exportation of United States aerospace technology to Japan in the 1950's and 1960's resulted from Japan's military decisions and its political climate. There are military advantages to local production of weapons, but even more important in Japan's case was the political controversy over importation of weapons. Because the aircraft manufactured in Japan were regarded as Japanese weapons, local support was generated for Japan's military strategy and force-level decisions.

It turned out, at least in the F-104J case, that the transfers were also economically advantageous. The costs of the Japanese-produced F-104Js were at least 10 per cent less than the probable cost had Japan bought the aircraft off the Lockheed production line. The benefits perceived when the decisions were made, however, were political rather than economic.

Regardless of whether economic, political, social, or some mixture of factors lead a firm or government to consider substituting an importation of technology for an importation of products, the costs of transfer are a factor in the decision and its outcome. These costs depend upon the amount of technology transferred and the process of acquisition.

At the start, costs depend on whether the transfer is limited to system-specific and firm-specific knowledge, or whether a substantial amount of general technology is required to establish the manufacturing capability. If the firm or country already possesses the general technology required to manufacture the product in question, transfer is likely to be relatively inexpensive. Transfers involving substantial amounts of general technology can be extremely expensive.

Even if the transplantation is limited to system-specific technology, transfer is not an all-or-nothing matter. The ability to import components, parts, and materials provides considerable flexibility in the extent of transfer. In the F-104J case, for example, the technology for the airframe was substantially transferred early in the C-1 program. However, the transfer of technology for the jet engine required practically all the C-1 program to complete, and little or no manufacturing technology for the electronics gear was transferred. Japanese involvement in electronics consisted of assembly of components and parts.

Transfer entails not only a movement of ideas in the form of blueprints, drawings, and other data, but a movement of material and men. Put differently, a transfer of manufacturing technology for a sophisticated product usually involves a transfer of rights and data, a technical assistance program, and material support. The success and costs of a transfer are importantly influenced by the amount of each class of support.

In the rights and data area, tooling designs and related information are particularly important. Much of the original producer's technology and learning advantages are embedded in his tools and the changes he makes to these tools. Transfer of tooling data, therefore, not only is essential to a technology transplantation, but it also influences the cost level that the new producer can achieve relative to the original producer.

Technical assistance is usually required since much technology, know-how, or learning is embodied in people rather than physical items. The amount and nature of technical assistance varied considerably in the Japanese aerospace co-production programs. The differences were partly related to the kind or amount of technology transferred. System-specific knowledge seemed to require much less personal contact than did firm-specific or general technology. In part, the differences appear to have reflected differences in corporate attitudes towards technical assistance. Since technical assistance accounts for a relatively small part of the costs of transfer, however, generous provision of it would seem an appropriate transfer tactic.

Material support may involve furnishing constructed tooling and other equipment, or it may be limited to hardcore imports of components, parts, and material. As we have seen, the hardcore list will contain items with opposite characteristics: low-cost, simple, standardized items on the one hand, and expensive, complex, and specialized items on the other. Decisions about the composition of the hardcore list can obviously lead to importing too much or too little technology, judged either by the costs of transferring the technology or by the total costs of the resultant products.

Costs of transfer are both direct and indirect. Direct costs include royalties, technical assistance payments, and similar expenses. Indirect costs occur because the establishment of a new production source affects production rates, total quantities of production at a single location, and schedules. Put differently, there are indirect cost impacts due to loss of scale or learning economies when production is divided into two locations. For the F-104J the direct costs amounted to about 7.8 per cent of the sales price of the aircraft. Indirect costs are harder to estimate, but it is clear that much of their impact was lessened by a substantial transfer of learning from Lockheed to Mitsubishi. Analysis of the progress curves of the two firms indicates that between 10 per cent and 25 per cent of Lockheed's accumulated learning was acquired by Mitsubishi as part of the technology transfer.

The expense required to transplant knowledge is a major determinant of international flows of technology. This case study of interfirm transfers of the manufacturing technology for a sophisticated product among firms in countries with developed economies is, of course, only one of many types of technology transfer. Intrafirm transfers by multinational corporations, transfers from highly developed to less-developed countries, and transfers of less sophisticated technologies, all have special cost characteristics different from those for the United States-Japanese aerospace transfers in the 1950's and 1960's. Nonetheless, technology transfer will require a process basically similar to that described here.

There will have to be transfers of rights, data, technical assistance, and material support. These will be direct costs involved in payments for these transfers, as well as indirect costs due to losses of advantages from economies of scale and learning impacts. More knowledge about the process for international transfers of technology and the cost relationships involved should enhance our understanding of international trade and investment and promote more effective public and private policies toward trade and investment.

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COMMENTS

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The Hall-Johnson paper contributes to our general understanding of the elements of comparative advantage in a spectrum of industrial activity. It analyzes the market structure and commercial considerations influencing the cost and feasibility of technological transfer. The paper also deals with the research and skill component in an array of industrial activity. The empirical evidence contained in the Hall-Johnson piece reinforces the view that Japan's ability to adapt and absorb foreign technology has been a basic ingredient of its competitive advantage in many areas of world trade. In our efforts to reformulate trade theory, this type of knowledge helps us to understand the technological component of traded goods and, more important perhaps, the ingredients of technological advantage.

Several characteristics of the Hall-Johnson paper warrant special mention. To begin with, not only does the paper deal with the required production time, resources, and capabilities, but it has also broken down the industrial product into components and parts. This is a significant step beyond the usual analysis based upon standard industrial classification product groups. Attention is drawn to the differences in technical sophistication and optimal scale requirements within product families and subassembly groups which affect comparative costs and manufacturing capability. In my own studies of diesel engine manufacture and automotive production,[1] I have found it is essential to analyze relative costs and technical requirements at the component and parts level.

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[1] *Manufacturing Problems in India,* Syracuse, 1967; and *Automotive Industries in Developing Countries,* World Bank Staff Occasional Paper No. 8, Baltimore, 1969.

Second, important distinctions are drawn in the paper among the various kinds of received technology—general, system-specific, and firm-specific. Implicit in this categorization are certain technical and commercial characteristics that affect both marketability as viewed by private corporations and the related cost and feasibility of transfer. The importance of these aspects are highlighted by Raymond Vernon, who has drawn attention to corporate earnings at various phases in the product cycle, and A. T. Knoppers, who analyzes profit motivation in transferring "marketable technology." [2] This, in part, is what is meant by "market force analysis of international flows of technology"—a market that has been structured by Japan's industrialization policies. The need for general versus system-specific or firm-specific knowledge depends upon the stage of sector development within each firm. Resource costs and phase-in time are also a function of the stage of industrial development. Japanese firms were apparently much further advanced in general airframe manufacturing technology than in aircraft electronics. In the electronics field, there was extensive need for general and system-specific knowledge as a prelude to the more costly and intricate firm-specific knowledge needed for actual production.

Firm-specific knowledge is an outgrowth of comparative development and experience. A longstanding policy of the Japanese government has been to give special subsidy or financial support to technologically weak sectors of the Japanese economy, and to expand or reinforce technical capabilities at the plant level. For example, the Japanese Development Bank finances projects to modernize plant equipment or develop new product designs with a view toward "enhancing the Japanese economy's competitive position in world trade."

A third point made in the Hall-Johnson paper relates to the components and parts that Japanese aircraft manufacturers continued to import rather than procure from local sources. These hardcore items included (1) sophisticated components or subassemblies that were

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[2] Raymond Vernon, "International Investment and International Trade in the Product Cycle," *The Quarterly Journal of Economics*, May 1966, pp. 190–207; Antonie T. Knoppers, "Development and Transfer of Marketable Technology in the International Corporation: A New Situation in Applied Science and World Economy" (paper presented to the Committee on Science and Astronautics, U.S. House of Representatives for the Ninth Meeting of the Panel on Science and Technology, February 1968), Washington, D.C., 1968, pp. 63–72.

difficult or expensive to transfer to domestic firms (such as special pumps and valves and electronic guidance devices), and (2) simple items (such as bolts and rivets that would be costly to reproduce domestically in limited quantities). From such evidence, two important insights emerge. First, industrial goods entering world trade depend in part upon the stage of development of the supply structure in overseas markets. Thus, protective tariffs nurture less efficient industries which displace industrial goods in world trade. Second, the development of local supplier capability is a function of domestic capabilities to adapt and absorb foreign technology. David Granick points out that Soviet metal-working plants in the 1930's had neither the technical skills nor the framework of industrial integration necessary to absorb the more advanced technologies then available from abroad.[3] In short, Japanese comparative advantage is something much more than cheaper labor. It is a composite of technological know-how, scale economies, and production strategies—the combination alluded to in Harry Johnson's illuminating "State of the Theory."

Much can be drawn from a study of this type about the nature of dynamic comparative advantage, the limitations of industrialization based upon import substitution, and the development of the technological ingredients for specialization in world trade. Defining the comparative advantage range as a contribution to long-term economic growth has been a topic of increasing concern in the field of development.[4] The technical and commercial considerations revealed in the Hall-Johnson paper need to be viewed in the broader context of trade and development policies which influence production costs and innovational environments. Harry Johnson has drawn attention to the stultifying effects of economic nationalism which often inhibit the development of indigenous technological capabilities.[5]

The Hall-Johnson paper draws attention to several other aspects affecting development strategies. Implicit in the Japanese experience are investments in research capabilities and technical skills to convert

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[3] David Granick, *Soviet Metal-Fabricating and Economic Development: Practice versus Policy*, Madison, Wisconsin, 1967.

[4] Wilfred Malenbaum, *et al.*, "Comparative Costs and Economic Development," *American Economic Review, Papers and Proceedings*, May 1964, pp. 390–434.

[5] Harry G. Johnson, *Economic Nationalism in Old and New States*, Chicago, 1966.

and absorb imported technology. I found in my study of diesel engine manufacture in India that the manufacturing capabilities that took less than two years to transfer to Japan will take at least fifteen years in India.[6] This is because there is a severe shortage in India of the critical engineering and technical skills that are much more abundant in Japan. High engineer density in Japan acts as a major contributing factor to the country's success in competing in world markets. Equally important is the technical assistance rendered to small supplier plants by the larger industrial firms in Japan. Foreign licensing regulations in Japan have also contributed to their success in world trade.[7]

Another revealing point made in this case study of technological transfer is the role played by multinational firms in imparting industrial design and manufacturing techniques. Much depends upon their willingness to share know-how, which is related to global marketing and manufacturing strategies. But even more important than the imparting of technical knowledge and manufacturing capabilities is the ability and willingness to implant indigenous engineering and design capability for continued technological transformation.[8]

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Apropos the comment of Jack Baranson regarding the adaptability of technology to local conditions, I would like to relate the example of how a certain radio manufactured in India with the assembly-line method turned out to contain several bugs in it because labor found it extremely difficult to adapt itself to the "moving line." A technology which was therefore appropriate to the transferring country was not optimal when

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[6] See Baranson, *Manufacturing Problems in India,* pp. 68–69.

[7] Terutomo Ozawa, *Imitation, Innovation, and Trade: A Study of Foreign Licensing Operations in Japan,* University Microfilms, 1967.

[8] Jack Baranson, "Transfer of Technical Knowledge by International Corporations to Developing Economies," *American Economic Review, Papers and Proceedings,* May 1966, pp. 259–67; see also Baranson, *Automotive Industries in Developing Countries,* pp. 79–80.

applied to the recipient country with different qualities in its labor force (although, given time, the labor force could almost certainly be trained up to the required level of discipline).

This example, in turn, raises the question as to why it was that such a technological transfer, presumably inefficient from an economic point of view, did not "lose out" in the competitive struggle. Or to put it in an alternative way, should economists really worry about such inefficient transfers if the market will make sure that they are eliminated by efficient transfers through the working of the market mechanism? In the Indian case, any such inefficient transfers showed surprising capacity to survive because the recipient country's policies frustrated the working of the market mechanism rather directly. Import controls prevented competition from abroad (through importation of competitively produced radios) whereas domestic restrictions on entry of new firms, via industrial licensing, prevented the emergence of more efficient rivals with superior technological processes. Thus, the existence of inefficient governmental policies elsewhere made it possible for firms to get away with importing inferior technologies. This conclusion, of course, begs the question as to why inferior technology should have been imported at all if better technology were available. In assessing this question, the facts that the market for sale of technology is imperfect and that information about alternatives not readily available are relevant.

Thus, in the end, the relevant questions seem to me to boil down to, *not* whether technology does get transferred at all, but whether the market for such transfers is perfect and, if it is not (in some defined sense), what is the pattern of optimal intervention that is called for. If the authors of the interesting paper on the transfer of aero-technology to Japan had focused on this question, we should have had answers of considerably greater interest to economists.