

TECHNOLOGY TRANSFER BY MULTINATIONAL FIRMS: THE RESOURCE COST OF TRANSFERRING TECHNOLOGICAL KNOW-HOW*

I. INTRODUCTION

The essence of modern economic growth is the increase in the stock of useful knowledge and the extension of its application. Since the origins of technical and social innovations have never been confined to the borders of any one nation, the economic growth of all countries depends to some degree on the successful application of a transnational stock of knowledge (Kuznets, 1966). In other words, the economic growth of every nation is inextricably linked to the successful international transfer of technology. Nevertheless, economists have been remarkably slow in addressing themselves to the economics of international technology transfer. The result is that "at both the analytic and factual level very little is known about the international transfer of knowhow" (Reynolds, 1966).

This paper addresses itself to this need. The starting-point is Arrow's suggestion that the cost of communication, or information transfer, is a fundamental factor influencing the world-wide diffusion of technology (Arrow, 1969).¹ The purpose of the paper is to examine the level and determinants of the costs involved in transferring technology. The value of the resources which have to be utilised to accomplish the successful transfer of a given manufacturing technology is used as a measure of the cost of transfer. The resource cost concept is therefore designed to reflect the ease or difficulty of transferring technological know-how from manufacturing plants in one country to manufacturing plants in another.

II. TECHNOLOGY TRANSFER AND THE PRODUCTION OF KNOWLEDGE

The literature on technological change recognises that it takes substantial resources to make a new process or product feasible (Mansfield, 1968). However, it is common to assume that the cost of transferring the innovation to other firms is very much less, so that the marginal costs of successive application is trivial compared to the average cost of research, development, and application. This paradigm is sometimes extended to international as well as domestic technology transfer (Rodriguez, 1975).² Buttressing this view is a common belief that

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¹ Arrow asks: "If one nation or class has the knowledge which enables it to achieve high productivity, why is not the other acquiring that information? . . . The problem turns on the differential between costs of communication within and between classes" (or nations). P. 33.

² "Transmission of technology between countries is assumed costless. Thus, it is possible for the

technology is nothing but a set of blueprints that is usable at nominal cost to all. Nevertheless, it has been pointed out that generally "only the broad outlines of technical knowledge are codified by non-personal means of intellectual communication, or communication by teaching outside the production process itself" (Berrill, 1964). The cost of transfer, which can be defined to include both transmission and absorption costs, may therefore be considerable when the technology is complex and the recipient firm does not have the capabilities to absorb the technology. The available evidence is unfortunately very sketchy. From the case studies of Mueller and Peck, Arrow inferred that transfer costs must be high (Arrow, 1962). From the Hall and Johnson study of the transfer of aerospace technology from the United States to Japan, it is not clear that this is true (Hall and Johnson, 1970). Robinson believes that economists' views on transfer costs are exaggerated (Robinson, 1973) while Mansfield and Freeman take the opposite view (Freeman, 1965; Mansfield, 1973). The lack of compelling evidence is apparent, and the appeals for further research (Mansfield, 1974; UNCTAD, 1970) seem to be well founded.

III. THE SAMPLE

The domain of this study is the transfer of the capability to manufacture a product or process from firms in one country to firms in another. Consequently the transfers can be considered as horizontal,¹ and in the design phase.² Data on 26 fairly recent international technology transfer projects were obtained. The proprietary nature of much of the data meant that sampling costs were high, which in turn severely limited the size of the sample that could be collected. All 26 transfers were conducted by firms which were multinational in the scope of their manufacturing activity, although they varied considerably in sales value (10–20 billion U.S. dollars) and R & D expenditures (1.2–12.5% of sales value). All had headquarters in the United States. The transferees were on the average much smaller and less research-intensive. In 12 instances they were wholly owned subsidiaries of the transferor, in 8 instances the transferor and transferee were joint ventures partners, in 4 instances transfers were to wholly independent private enterprises, and the remaining 3 were to government enterprises. Table 1 shows that 17 of the projects fall into a broad category which will be labelled "chemicals and petroleum refining." The remaining 9 projects fall into a category which will be labelled "machinery".³ Table 1 also indicates the wide geographical dispersion of the transferees.

country which owns the technology to operate a plant in a foreign country without any transfer of factors." P. 122.

¹ Horizontal transfer refers to the transfer of technical information from one project to another. It can be distinguished from vertical transfer, which refers to the transfer of technical information within the various stages of a particular innovation process, e.g. from the basic research stage to the applied research stage.

² For the distinctions between materials transfer, design transfer, and capacity transfer, see Hayami and Ruttan (1971).

³ Chemicals and petroleum refining thus embrace ISIC categories (United Nations, 1968), 351, 353, and 356, while "machinery" embraces categories 381, 382, and 383.

Table 1
Twenty-six Technology Transfer Projects: 3 Digit ISIC Category and Transferee Location

Location	"Chemicals and Petroleum Refining"			"Machinery"			Total
	351: industrial chemicals	353: petroleum refineries	356: plastic products	381:	382:	383:	
				fabricated metal products machinery and equipment	machinery except electrical	electrical machinery, appliances, and supplies	
Canada	1	1	0	1	0	0	3
Northern and Western Europe	3	1	0	0	4	1	9
Australia	0	0	1	0	0	0	1
Japan	3	0	0	0	1	0	4
Eastern Europe	2	0	0	0	0	0	2
Latin America	3	0	0	0	0	1	4
Asia (excluding Japan)	0	1	0	0	0	1	2
Africa	1	0	0	0	0	0	1
Total	13	3	1	1	5	3	26

IV. DEFINITION OF TECHNOLOGY TRANSFER COSTS

An economic definition of transfer cost is developed below. The emphasis is on the resources which must be utilised to transfer technological know-how. Of course royalty costs or rents must be incurred merely to secure access to the technology, but these costs are not the focus of attention of this paper.¹ In order to appreciate the import of the definition that will be presented, a distinction must first be made between two basic forms in which technology can be transferred. The first form embraces physical items such as tooling, equipment, and blue prints. Technology can be embodied in these objects. The second form of technology is the information that must be acquired if the physical equipment or "hardware" is to be utilised effectively. This information relates to methods of organisation and operation, quality control, and various other manufacturing procedures. The effective conveyance of such "peripheral" support constitutes the crux of the process of technology transfer, and it typically generates the associated information flows. It is towards discovery of the cost of transfer of this "unembodied"² knowledge that the attention is directed.

Technology transfer costs are therefore defined as the costs of transmitting and absorbing all of the relevant unembodied knowledge. The costs of performing the various activities which have to be conducted to ensure the transfer of the necessary technological know-how will represent the cost of technology transfer.³ Clearly, a great many skills from other industries (e.g. design engineering) will be needed for plant design, plant construction, and equipment installation. However, not all of these skills will have to be transferred to ensure the success of the project. As defined, the costs of transfer clearly do not include all of the costs of establishing a plant abroad and bringing it on stream.

The definition of transfer costs presented at the conceptual level can be translated into operational measures by considering the nature of a given project activity. At the operational level the subset of project costs identified as transfer costs fall into four groups. The first group is the cost of pre-engineering technological exchanges. During these exchanges the basic characteristics of the technology are revealed to the transferee, and the necessary theoretical insights are conveyed. The second group of costs included are the engineering costs associated with transferring the process design and the associated process engineering⁴ in the case of process innovations, or the product design and production engineering⁵ in the case of product innovations. If the technology has already

¹ Many observers equate the cost of technology with royalty fees (Mason, 1973; Gillette, 1973). Royalty costs are considered in the dissertation from which this paper was taken.

² Unembodied knowledge is the term used here to denote knowledge not embodied in capital goods, blueprints, and technical specifications, etc.

³ All of the relevant costs are included, irrespective of which entity initially or eventually incurs them.

⁴ Process engineering for continuous flow technology involves the compilation of flow diagrams, heat balances, control instrumentation, etc. It can be distinguished from detailed engineering which involves the translation and elaboration of the process engineering into a manufacturing facility.

⁵ Production engineering for a specified item can be divided into two phases: production design and process planning. Production design is the modification of the functional design in order to reduce manufacturing costs. (Functional product design is the design of a product to fulfil certain specifications and requirements.) Given the design, process planning for manufacture must be carried out to specify,

been commercialised,¹ transmission may simply involve transferring existing drawings and specifications with the minimum of modification. However, the process of absorption may be more difficult, requiring the utilisation of considerable consulting or advisory resources. "Engineering" costs not falling into the specified categories² are excluded from transfer costs. The excluded engineering costs are essentially the plant or detailed engineering costs, net of advisory or consulting costs. This residual is assumed to correspond with routine drafting costs. Routine drafting is generally performed by technicians under the supervision of engineers. Drafting skills do not have to be transferred for the viability of the project to be assured. Accordingly, drafting is not considered to represent a transfer activity.³

The third group of costs are those of R & D personnel (salaries and expenses) during all phases of the transfer project. These are not the R & D costs associated with developing the underlying process or product innovations. Rather, they are the R & D costs associated with solving unexpected problems and adapting or modifying the technology. For instance, research scientists may be utilised during the transfer if new and unusual technical problems are encountered⁴ with the production inputs. These R & D costs are generally small or non-existent for international transfers falling into the "design transfer" category.

The fourth group of costs are the pre-start-up training costs and the "excess manufacturing costs". The latter represent the learning and debugging costs incurred during the start-up phase, and before the plant achieves the design performance specifications. It is quite possible that no marketable output will be produced during the initial phases of the start-up. Nevertheless, normal labour, materials, utilities, and depreciation costs will be incurred, together with the costs of the extra supervisory personnel that will inevitably be required to

in careful detail, the processes required and their sequence. The production design first sets the minimum possible costs that can be achieved through the specification of materials, tolerances, basic configurations, methods of joining parts, etc. Process planning then attempts to achieve that minimum through the specification of processes and their sequence to meet the exacting requirements of the design specifications. The accepted end-point for production design is manifested by the drawing release. Process planning takes over from this point and develops the broad plan of manufacture of the part or product. A distinction can also be drawn between process planning and the layout of the physical facilities. Some process planning will take place during the layout phases of the design of a production system. Process plans can be regarded as inputs to the development of a layout. (*McGraw-Hill Encyclopedia*, 1960.)

¹ An innovation is said to have been commercialised if it has already been applied in a facility of economic size which is essentially non-experimental in nature. Thus pilot plant or prototype application is not considered to represent commercialisation.

² These categories are (a) process or design engineering costs and related consultation for process innovations or (b) production engineering expenses for product innovations; and (c) costs of engineering supervision and consultation (salaries plus travel and living) for the plant engineering.

³ Drafting costs can be considered an implementation cost rather than a transfer cost, the implication being that if the host country does not have these skills, the viability and cost of the project is unlikely to be affected. The advisory and consulting costs, on the other hand, represent transfer costs since these activities are necessary if the technology is to be adjusted to the local circumstance and requirements. Clearly, if an existing plant was to be duplicated in its own environment, consulting costs could be expected to go to zero, whereas routine drafting would still have to be performed.

⁴ Referring to process technologies, it is possible that differences in feedstocks amongst various locations may create problems that only research scientists can effectively handle. Similarly, changes in atmospheric conditions or water supply could have unexpected consequences for some highly complex processes.

assist in the start-up. The operating losses incurred during initial production are very often a close approximation to excess manufacturing costs.¹

V. TRANSFER COSTS: DATA AND HYPOTHESES

1. *The Level of Transfer Costs*

The above definition was used to calculate the transfer costs for 26 projects. The results are presented in Table 2. The costs are given in absolute dollars, and then normalised by total project costs.² For the sample as a whole, transfer costs average 19 % of total project costs. Clearly, the data do not support the notion that technology is a stock of blueprints usable at nominal cost to all. Nevertheless, there is considerable variation in the sample data, with transfer costs ranging from 2 % to 59 % of total project costs. The number of factors influencing transfer costs is undoubtedly very great,³ but some factors are likely to have a more pervasive influence than others. The discussion to follow is restricted to hypotheses for which statistical testing is feasible, given the available data. Two groupings of testable hypotheses can be identified: characteristics of the technology/transferor, and characteristics of the transferee/host country.

2. *Technology/Transferor Characteristics*

A critical factor in the transfer of technology is the extent to which the technology is completely understood by the transferor. The number of manufacturing start-ups⁴ or applications which the transferor has already conducted with a specific technology can be used as an index of this knowledge.⁵ An increase in the number of applications is likely to lower transfer costs since with each start-up additional knowledge about the technology is acquired. Since no two manufacturing start-ups are identical, each start-up provides the firm with the opportunity to observe the effects of different operating parameters and differences in equipment design. Each application can be regarded as a new experiment which

¹ An important consideration is the extent to which excess manufacturing costs correctly reflect technology transfer costs rather than the costs of discovering and overcoming the idiosyncrasies of a new plant. One way to confront this issue is to consider the level of excess manufacturing costs when an absolutely identical plant is constructed in a location adjacent to an existing plant. Further, assume the second plant embodies the same technology as the first plant, and the labour force from the first is transferred to the second for the purpose of performing the manufacturing start-up. The assumption is that under these circumstances excess manufacturing costs in the second plant will be zero, or very nearly so. The correctness of this assumption was corroborated by a subsample of project managers subsequently questioned about this matter. The postulated circumstance would be identical to shutting down the first plant and then starting it up again. Some excess manufacturing costs might be incurred during the initial hours of operation if the plant embodies flow process technology. (For the projects in the sample the average duration of the manufacturing start-up was 8.2 months.) However, these costs are unlikely to be of sufficient magnitude to challenge the validity of classifying excess manufacturing costs as a component of technology transfer costs.

² Total project costs are measured according to the inside boundary limits definition commonly employed by project accountants. Installations outside the plant perimeter are thereby excluded.

³ For a broader view of the spectrum of hypotheses, see the author's Ph.D. dissertation.

⁴ Manufacturing start-ups are synonymous with the number of applications of the technology. If a new plant is built for each application, it would also be synonymous with the number of plants that are built which utilise the technology.

⁵ Corporations engaged in technology transfer ventures not grounded on their own technology are known to have encountered massive transfer problems and costs.

yields new information and new experience.¹ Transfer will be facilitated the more fully the technology is understood. Besides these engineering economies, additional applications provide expanded opportunities for the pre-start-up, training of the labour force. Clearly, if identical or similar plants exist elsewhere,

Table 2

Sample Data on the Resource Costs of Technology Transfer: 26 International Projects

Chemicals and Petroleum Refining		Machinery	
Transfer costs: dollar amount (thousands)	Transfer costs: dollar amount total project cost	Transfer costs: dollar amount (thousands)	Transfer costs: dollar amount total project cost
49	18	198	26
185	8	360	32
683	11	1,006	38
137	17	5,850	45
449	8	555	10
362	7	1,530	42
643	6	33	59
75	10	968	24
780	13	270	45
2,142	6		
161	2		
586	7		
877	7		
66	4		
2,850	19		
7,425	22		
3,341	4		

then experienced operators from these plants can be used to assist the start-up in the new plant. In addition, untrained operators can be brought into existing plants for pre-start-up training.

The second variable to be considered is the age of the technology. The age of the technology is defined as the number of years since the beginning of the first commercial application of the technology² anywhere in the world, and the end³ of the technology transfer programme. The age of an innovation will determine the stability of the engineering designs and the transferor's knowledge of the manufacturing procedures. The older the technology, *ceteris paribus*, then the greater have been the opportunities for interaction between the development groups and the manufacturing and operating groups within the firm. Problems

¹ The first application represents first commercialisation of the technology. This will result in the creation of a set of basic engineering drawings and specifications. Duplication and alteration of these for subsequent start-ups will involve a modest cost compared to the initial cost of constructing them.

² If there is more than one key innovation embodied in the technology, then the date of commercial application of the most recent key innovation is the reference date.

³ Age is defined up to the end of the transfer programme since any knowledge about the technology acquired up to this point is potentially useful for the transfer. For the very first start-up, age will be the length of the transfer minus the development overlap.

stand a better chance of already being ironed out, and the drawings are likely to be more secure. Further, since technology is not embodied in drawings alone, there is a great deal of uncoded information – the relevant “art”. This kind of knowledge is carried by the supervisors, engineers, and operators. As the age of the technology increases, more individuals in the firm have the opportunity to acquire this non-codified information, and hence are potentially available to assist in the transfer. There will, however, be some point after which greater age will begin to increase the cost of transfer. When the length of stay of corporate personnel begins to be outstripped by the age of technology, then the non-codified dimensions of design knowledge may be lost to the firm.¹

It is necessary to distinguish the cost reductions resulting from additional start-ups from the cost reductions resulting from greater age of the technology. For continuous flow technologies, additional applications of an innovation in entirely new plants will allow experimentation with scale and with the basic parameters of the design. This will generate a greater understanding of the technology. On the other hand, greater age, given the number of applications or start-ups, generally permits experimentation only with operating parameters, the design of the plant remaining fixed throughout.

The third technology variable to be considered is the number of firms utilising the technology, or one that is “similar and competitive”. This is taken to represent the degree to which the innovation and the associated manufacturing technology is already diffused throughout the industry. The greater the number of firms with the same or similar and competitive technology, then the greater the likelihood that technology is more generally available, and can therefore be acquired at lower cost.²

These technology variables and the attendant hypotheses begin to take on some extra significance when viewed together. Taken singly they define the technology to only a limited degree. Together, they hypothesise, *ceteris paribus*, that the most difficult and hence costly technology to transfer is characterised by very few previous applications, a short elapsed time since development, and limited diffusion. Technology displaying such characteristics can be termed “leading-edge” technology. “Leading-edge” technology is likely to be in a state of flux; the engineering drawings will be constantly altering, thus frustrating the transfer. In comparison, state-of-the-art technology is hypothesised, *ceteris paribus*, to involve lower transfer costs since the engineering drawings are more likely to be finalised and the fundamentals of the technology stand a better chance of being more fully understood.

¹ In the limit, the firm could terminate its utilisation of a particular technology, and the non-codified information associated with it could be gradually lost for ever as the technology becomes historic. Further, the drawings associated with technology that is very old may suffer from so many small alterations that the very essence of even the codified technology may become quite obscure. Since none of the technology transfer projects in the sample were historic in the above sense, the relevant range of the hypothesised age-transfer cost function involves an inverse relationship between the age of the technology and the cost of transfer.

² An identification problem may exist here because more firms may have applied the technology because the transfer cost is low.

3. *Transferee and Host Country Characteristics*

The technical and managerial competence of the transferee will be presented as an important determinant of the ease with which technology can be absorbed. The years of manufacturing experience of the transferee in a given 4-digit ISIC industry (United Nations, 1968) is used as an index of the extent to which managers, engineers, and operators have command over the general manufacturing skills of an industry. A firm skilled in the manufacture of a group of products is likely to have less difficulty absorbing a new innovation in that industry group than is the firm which has had no previous experience manufacturing products in a particular industry group (Rawski, 1975). Older enterprises, with their skilled manufacturing personnel, seem more likely to be able to understand and apply codified knowledge to the manufacture of a new product, or the utilisation of a new process.¹

Another variable to be considered is the size of the transferee. Although less compelling, the reasoning behind the hypothesis that transfer costs decline with firm size is that larger firms generally have a wider spectrum of technical and managerial talent which can be called on for assistance during the transfer. A small firm may be technically and managerially quite competent yet unable to absorb new technology easily because of the extra demands placed on its scarce managerial and technical manpower. Consultants may have to be engaged by the smaller firms to perform tasks that are typically handled internally in larger firms.

A third variable considered is the R & D activity of the transferee. When unusual technical problems are unexpectedly encountered, an in-house R & D capability is likely to be of value. Oshima has argued that the R & D capability of Japanese firms facilitated the low-cost importation of foreign technology by Japanese firms (Oshima, 1973). The R & D to sales ratio of the transferee is taken as an index of its R & D capability, and an inverse relationship between this and transfer cost is postulated.

The final variable considered is designed to reflect the level of development of the host country infrastructure, which is hypothesised to be a determinant of the cost of transfer. For example, the level of skill formation in the host country will influence the amount and type of training that the labour force will require. Similarly, if the new venture is to acquire its inputs domestically, the quality of the inputs available will undoubtedly influence the level of start-up costs. There are many other considerations of similar kind which could be discussed. However, the high degree of cross-sectional collinearity between indices of development (Kuznets, 1966) makes the identification of separate effects statistically difficult. However, GNP *per capita*, a measure of productive capacity, can

¹ According to Rawski, recent experience of the People's Republic of China shows that during at least some phases of industrialisation, production experience may be a key determinant of the level and fungibility of industrial skills. Rawski notes that "with their skilled veteran workers and experienced technical persons, old industrial bases and old enterprises find it easier to tackle complicated technical problems than new enterprises and new industrial bases. With these advantages, it is the established centers which are best able to copy foreign equipment samples, to extract useful information from foreign technological publications, and to apply it to current domestic problem areas." (Rawski (1975), p. 386.)

be expected to capture some of the above considerations, and it will be used in this study as an index of economic development. A negative relationship between transfer cost and GNP/*per capita* is postulated.¹

VI. DETERMINANTS OF THE COST OF INTERNATIONAL TECHNOLOGY TRANSFER: TESTS AND RESULTS

1. *The Model*

The basic model to be tested is

$$C_i = f(U_i, G_i, E_i, R_i, S_i, N_i, P_i, Z_i), \quad (1)$$

where C_i is the transfer cost divided by the total project cost for the i th transfer; U_i is the number of previous applications or start-ups that the technology of the i th transfer has undergone by the transferor;² G_i is the age of the technology in years; E_i is the number of years of manufacturing experience that the recipient of the i th transfer has accumulated; R_i is the ratio of research and development to sales for the recipient of the i th transfer, calculated for the year the transfer commenced; S_i is the volume of sales, measured in millions of dollars, of the recipient of the i th transfer; N_i is the number of firms identified by the transferor as having a technology that is identical or "technically similar and economically competitive" to the technology underlying the i th transfer; P_i is the level of GNP *per capita* of the host country (International Bank, 1973); Z_i is the random error term for the i th transfer. The expected derivatives are:

$$\frac{\partial C_i}{\partial U_i} < 0, \quad \frac{\partial C_i}{\partial G_i} < 0, \quad \frac{\partial C_i}{\partial E_i} < 0, \quad \frac{\partial C_i}{\partial R_i} < 0, \quad \frac{\partial C_i}{\partial S_i} < 0, \quad \frac{\partial C_i}{\partial N_i} < 0, \quad \frac{\partial C_i}{\partial P_i} < 0.$$

Since one of the best tests of any hypothesis is to look for the convergence of independent lines of evidence, the testing of this model will proceed in two phases. First, cross-section data on 26 completed projects is utilised in a linear version of the model estimated by ordinary least-squares procedures. Secondly, cost estimates provided by project managers for comparable projects are pooled to test a more specific non-linear version of the model.

2. *Statistical Tests: Phase 1*

The model to be tested is

$$C_i = \alpha_0 + \alpha_1 \bar{U}_i + \alpha_2 G_i + \alpha_3 E_i + \alpha_4 R_i + \alpha_5 S_i + \alpha_6 N_i + \alpha_7 P_i + Z_i, \quad (2)$$

where \bar{U}_i is a dummy variable taking the value 1 if the transfer represents the first manufacturing start-up, and zero otherwise. \bar{U}_i is used rather than U_i for empirical reasons, since the first start-up is often of critical importance. The sample was dichotomised because of the large differences between continuous flow process technology, and product technology. One category includes chemicals and petroleum refining and the other includes machinery (see Table 1).

¹ The sample did not include countries where high GNP statistics were grossly dependent on oil revenues.

² The number of previous manufacturing start-ups was significant in Phase 1 only when it was included as a dummy variable taking the value 1 if there had been no previous manufacturing start-ups of this technology by the transferring firm, and zero otherwise.

The results in Table 3 indicate that in chemicals and petroleum refining \bar{U}_i , N_i , and E_i are significant at the 0.05 level and carry the expected signs. In the machinery category the variables N_i , G_i , and E_i all carry the expected signs and are significant at the 0.05 level. N_i and E_i are thus significant in both industry

Table 3
Regression of Coefficients and *t* Statistics in Regression
Equations to Explain *C* (The Cost of Transfer)

Independent variable	Chemicals and petroleum refining		Machinery	
	Equation (1)*	Equation (2)*	Equation (1)*	Equation (2)*
Constant	12.79 (6.82)	13.42 (6.98)	16.67 (8.27)	65.98 (6.60)
Novelty dummy variable \bar{U}_i †	6.73 (1.92)	6.11 (1.75)	—	1.62 (0.15)
Number of firms variable	-0.37 (-2.06)	-0.39 (-2.22)	-1.29 (-2.28)	-1.26 (-1.95)
Age of technology variable (years)	—	—	-2.43 (-3.53)	-2.35 (-2.51)
Experience of transferee variable (years in 4-digit ISIC)	-0.09 (-1.66)	-0.08 (-1.42)	-0.84 (-3.37)	-0.85 (-2.95)
Size of transferee variable (thousands of dollars of sales)	—	-0.0009 (-1.18)	—	—
Number of observations	17	17	9	9
R^2	0.56	0.61	0.78	0.78
<i>F</i>	5.66	4.73	6.00	3.22
Significance level of <i>F</i>	0.01	0.02	0.04	0.12

* Omitted coefficient indicates variable dropped from the regression equation.

† Note 2, p. 251.

groupings, strongly supporting the hypothesis that transfer costs decline as the number of firms with identical or "similar and competitive" technology increases, and as the experience of the transferee increases. However, R_i and P_i were not significant in any of the equations, and although S_i carries the expected sign and approaches significance in one of the regressions it is not possible to be more than 85 % sure that the sign is correct or that the coefficient is different from zero.¹

¹ Multicollinearity does not appear to be a serious problem in any of the equations. Correlations amongst pairs of the independent variables were never significant at the 0.05 level. The stability of the regression coefficients further suggests that multicollinearity is not a serious problem. Dummy variables were introduced to test for the effects of the organisational relationship between transferor and transferee (affiliate/non affiliate, public enterprise/private enterprise), but they were not found to be statistically significant determinant of transfer costs. Application of a forward step by step procedure did not reveal a preferred subset of variables. However, it is possible that the correct model is the simultaneous equation model $C_i = f(N_i, \dots)$, $N_i = f(C_i, \dots)$. To eliminate simultaneous equation bias it would be desirable to use a two-stage procedure. A predictor of N could first be obtained by regressing N_i on arguments other than C_i . This could then be used as an argument in the transfer cost regression. It was not possible to obtain a good predictor of N using the available cross-section data, so this procedure was not employed. Consistency was sacrificed for efficiency. It is therefore possible that simultaneous equation bias remains in the model. Therefore, the estimates of the parameters may not be consistent.

The results therefore generally support the hypotheses advanced earlier, but there are differences in the size of coefficients as well as in the specification of the equations between the industry groups. In particular, the novelty variable \bar{U}_i is significant in chemicals and petroleum refining, but insignificant in machinery. The converse is true for the age variable G_i . The reason may be that there exists relatively less latitude for production experimentation with continuous flow process technology than with product technology. Once the plant is constructed, the extent to which the design parameters can be changed is rather minimal because of the degree of interdependence in the production system. In comparison, many product technologies allow greater design flexibility. Innumerable small changes to the technology are very often possible without massive reconstruction of the plant. It is also of interest that the coefficient of the experience variable E_i is considerably larger in machinery than in chemicals and petroleum refining. This is consistent with other findings that reveal important learning economies in fabrication and assembling (Tilton, 1971).

3. *Statistical Tests: Phase II*

The above analysis is handicapped by the small sample size and the very high costs of adding additional observations. Limited variation in exogenous variables coupled with the problem of omitted variables can imply difficulties with bias and identification. For the projects in the sample, a procedure was therefore devised to hold the missing variables constant while generating large variation in the exogenous variables. The respondent firms were asked to estimate how the total transfer costs would vary for each project if one particular exogenous variable happened to take a different value, assuming all other variables remain constant. The responses were taken into account only if the exercise generated circumstances within the bounds of an executive's experience. Given these limitations, the change specified was quite large in order to provide a robust sample. Generally the actual value of a selected variable was hypothesised first to halve and then to double. The estimated impact on transfer costs was noted. The exercise was performed for the following independent variables: the number of applications or start-ups that the technology has undergone; the age of the technology; the number of years of previous manufacturing experience possessed by the transferee in a given four-digit industry; the research and development expenditures to sales ratio for the transferee; the size (measured by sales value) of the transferee. For each variable this exercise generated at most three observations (including the actual) or transfer costs for each project. Pooling across projects produces enough observations for ordinary least-squares regression analysis.

The estimation procedure is commenced by assuming that the shape of the cost function can be represented by the following relatively simple but quite specific equation

$$C_j = V e^{\phi_j X_j} \quad (3)$$

C is the estimated transfer cost as a percentage of total project cost, X represents the value of various independent variables, j refers to the j th observation.

With this specification, the transfer cost for a project asymptotically approaches a minimum non-zero value as the value of each X increases. That is, as X goes to infinity, C goes to V . Therefore V is the minimum transfer cost with respect to the X variable. However, there is no maximum cost asymptote for the range of the data. The expression for the elasticity of transfer cost with respect to X is given by

$$\frac{-X}{C} \frac{dC}{dX} = \frac{\phi}{X}. \quad (4)$$

Thus for a specified value of X , the elasticity of transfer cost with respect to X is determined by ϕ . Hence the elasticity depends only on ϕ and X . In order to estimate the function, the log of the arguments in (3) are taken:

$$\log C_j = \log V + \frac{\phi}{X_j}. \quad (5)$$

Dummy variables are used to pool the observations across projects. Inclusion of dummy variables allows the minimum cost asymptote to vary from project to project. It is assumed that ϕ is constant across projects. These assumptions provide a pooled sample with intercepts which vary across projects.

Ordinary least-squares regressions of $\log C_j$ on the dummy variables and $1/X_j$ then proceeded for five different X variables, and for five data sets. These were: total transfers; transfers within the chemical and petroleum refining category; transfers in the machinery category; transfers of chemicals and petroleum refining technology to developed countries; and transfers of chemical and petroleum refining technology to less developed countries.¹ The Chow test (Chow, 1960) of equality between sets of coefficients in two linear regressions revealed that the separation of the sample along industry lines was valid, except for the research and development variable. However, there was no statistically valid reason for disaggregating the chemical and petroleum refining subsample according to differences in GNP *per capita* in the host countries.

The results of the estimation are contained in Table 4. The high R^2 values are partly because the large across-project variation in costs is being captured by the project dummies. The intercept term was always highly significant and the coefficients on all the dummies were significantly different from each other. All of the coefficients are significantly greater than zero at the 0.20 level and the age of the technology, the number of manufacturing start-ups, transferee size and experience achieve at least the 0.05 significance level in one or other of the subsamples. In several cases the coefficients are highly significant, providing strong statistical support for the hypotheses that have been advanced. The number of previous applications once again has a sizeable impact. Diffusion and manufacturing experience are particularly important in the machinery category.

The calculation of elasticities allows interpretation and comparisons of estimated effects. Average or point elasticities for some typical sample values of X are presented in Table 5. These estimates suggest that in the chemicals and petroleum-refining category, the second start-up could lower transfer costs by

¹ A purely arbitrary classification was used where less developed countries were defined as those with GNP/*per capita* less than \$1,000.

34 % over the first start-up, other variables held constant. The corresponding change for conducting a third start-up is 19 %. The other elasticities can be interpreted similarly.

Table 4

Estimated values of ϕ (obtained from regressing $\log C_i$ on $\log V + \phi/X_j$) together with corresponding t -statistics, sample size, degrees of freedom, and coefficient of determination R^2

Variable	ϕ	t -statistic	Sample size	Degrees of freedom	R^2
Start-ups					
Chemicals and petroleum refining	0.46	4.23	45	25	0.92
Machinery	0.19	1.76	20	10	0.91
Age					
Chemicals and petroleum refining	0.04	1.29	47	30	0.89
Machinery	0.41	2.19	21	13	0.94
Experience					
Chemicals and petroleum refining	0.007	0.85	52	33	0.78
Machinery	0.57	6.08	23	14	0.91
Size					
Chemicals and petroleum refining	0.008	1.17	54	35	0.88
Machinery	0.081	5.18	17	10	0.99
R & D sales					
Total sample	0.06	1.58	59	30	0.90

VII. DIFFERENCES BETWEEN INTERNATIONAL AND DOMESTIC TECHNOLOGY TRANSFER

Although this is primarily a study of international technology transfer, it is apparent that many of the characteristics of international technology transfer are also characteristic of the technology transfer that occurs within national borders, but there are differences. For instance, distance and communication costs very often differentiate international from domestic transfers. Although the communications revolution of the twentieth century has enormously reduced the barriers imposed by distance,¹ the costs of international communication are often significant.² Language differences can also add to communication costs, especially if the translation of engineering drawings is required. The experience of Polyspinners Ltd at Mogilev in the Soviet Union (Jones, 1973) is ample testimony to the extra costs that can be encountered.³ International differences in units of measurements and engineering standards can compound the problems encountered (Meursinge, 1971). Additional sources of difficulty are rooted in

¹ Facsimile equipment exists which can be used to transmit messages and drawings across the Atlantic instantaneously.

² One of the participating companies indicated that travel, telegraph, freight, and insurance added about 10 % to the total cost of a project established in New Zealand.

³ The project manager estimated that documentation alone cost £500,000, and the translation a similar amount.

the cultural and attitudinal differences between nations, as well as differences in the level of economic development and the attendant socioeconomic structure.

It is of interest to know the magnitude and determinants of the "international component" of the transfer cost. Unfortunately, foreign and domestic transfers

Table 5
*Arc or Point Elasticity of Transfer Costs With Respect to Number of Start-ups,
Age of Technology, Experience, Size and R & D/Sales of Transferee*

Independent variable	Chemicals and petroleum refining	Machinery
	Arc elasticity	
Number of start-ups		
1-2	0.34	0.14
2-3	0.19	0.08
3-4	0.13	0.05
9-10	0.05	0.02
14-15	0.03	0.01
	Point elasticity	
Age of technology (years)		
1	0.04	0.41
2	0.02	0.20
3	0.01	0.14
10	0.00	0.04
20	0.00	0.02
	Point elasticity	
Experience of transferee (years)		
1	0.007	0.57
2	0.003	0.28
3	0.002	0.19
10	0.001	0.06
20	0.000	0.03
	Point elasticity	
Size of transferee (millions of sales dollars)		
1.0	0.008	0.081
10	0.001	0.008
20	0.000	0.004
100	0.000	0.001
1000	0.000	0.000
	Total sample point elasticity	
R & D/Sales of transferee (%)		
1	0.06	
2	0.03	
3	0.02	
4	0.01	
5	0.01	
6	0.01	

are rarely identical in scope or in timing, and so it is not possible to gather comparative data on implemented projects at home and abroad. It was therefore found necessary to rely on estimates provided by the firms involved in international transfers. For the projects in the sample, project managers were asked to estimate the dollar amount by which transfer costs would be different if the

international transfers in the sample had occurred domestically, holding firm and technology characteristics constant. The procedure was designed to highlight the effects of country characteristics such as differences in language, differences in engineering and measurement standards, differences in economic infrastructure and business environment, and geographical distance from the transferor. The international component of the transfer cost for the projects in the sample could be obtained by subtracting the estimated transfer cost from the

Table 6
International Component of Transfer Cost*

Chemicals and petroleum refining		Machinery	
Dollar amount (thousands)	As % of actual transfer cost	Dollar amount (thousands)	As % of actual transfer cost
3.03	6.07	35.55	17.88
0.00	0.00	-399.37	-110.93
-12.81	-1.87	50.06	4.93
43.90	31.00	830.70	14.20
0.00	0.00	-4.59	-0.02
5.17	1.42	226.80	14.82
132.75	20.63	0.67	1.99
0.00	0.00	-134.40	13.87
342.00	43.84	34.98	12.95
0.00	—		
0.00	—		
0.00	0.00		
-10.77	-6.66		
-50.16	-8.52		
0.00	—		
637.32	72.60		
-1.33	-1.99		
1,723.81	60.48		
1,370.25	18.45		
524.25	15.69		

* Amount of actual transfer costs attributable to the fact that transfer was international rather than domestic. (Accordingly negative values indicate that firms estimated that transfer costs would be higher had the transfer been domestic.) In general, these numbers were derived from taking the weighted average of estimated changes in the various identifiable components of transfer costs.

actual transfer cost. The data, contained in Table 6, reveal that the difference in cost is not always positive. This indicates that in at least some of the cases, the international transfer of an innovation was estimated to cost less than a comparable domestic transfer. This may seem paradoxical at first, given that international technology transfer generally augments the transfer activities that have to be performed.¹ An analysis of the determinants of the international component of transfer costs may yield an explanation.

Several hypotheses are presented and tested. The first is that the difference is

¹ The source of the apparent paradox may be differences in labour costs. Nevertheless, the identification of the transfer for which international transfer costs less than domestic transfer is an issue of importance.

large and positive when the technology has not been previously commercialised. National boundaries are often surrogates for cultural and language barriers, differences in methods and standards of measurement, and distance from the home country. During first commercialisation of a product or process, there are generally enormous information flows across the development-manufacturing interface. The hypothesis is that placing a national boundary at this interface can complicate matters considerably, and escalate the costs enormously. The second hypothesis is that transfers to government enterprises in centrally planned economies will involve higher transfer costs. Transferors can expect numerous delays and large documentation requirements (Jones, 1973). The third hypothesis is that the less the diffusion of the technology, measured as before by the number of firms utilising the innovation, the greater the positive differential associated with international technology transfer. The fourth hypothesis is that whereas, in general, low levels of economic development are likely to add to transfer costs because of inadequacies in the economic infrastructure, this may be more than offset, in some circumstances, by low labour costs. Labour costs can have a substantial impact on excess manufacturing costs, especially in relatively labour intensive industries. Since machinery manufacture is relatively labour intensive, the hypothesis is that the GNP *per capita* in the host country is positively related to the transfer cost differential in this classification, but is negatively associated with the differential in the chemicals and petroleum refining category.

To test these hypotheses it is assumed that

$$D_i = \alpha_0 + \alpha_1 d_i + \alpha_2 \bar{U}_i + \alpha_3 N_i + \alpha_4 P_i + Z_i,$$

where D_i is the "international component" as a percentage of actual transfer cost for the i th transfer. d_i is a dummy variable which takes the value 1 if the recipient of the i th transfer is a government enterprise in a centrally planned economy, and zero otherwise. The other variables carry the same definitions as previously. The expected derivations are:

$$\frac{\partial D_i}{\partial d_i} > 0, \quad \frac{\partial D_i}{\partial \bar{U}_i} > 0, \quad \frac{\partial D_i}{\partial N_i} < 0;$$

$\partial D_i / \partial P_i \gtrless 0$ according to the industry category (the partial is postulated positive for the machinery category, and negative otherwise). Least-squares estimates of the α 's were obtained, the results being:

Chemicals and petroleum:

$$D_i = 0.285 + 3.84d_i + 4.46\bar{U}_i \quad (n = 17, r^2 = 0.71). \\ (0.91) \quad (5.01) \quad (4.89)$$

Machinery:¹

$$D_i = -8.59 - 1.39N_i + 0.005P_i \quad (n = 9, r^2 = 0.94). \\ (-1.96) \quad (-5.98) \quad (3.90)$$

¹ O_i was omitted from the machinery regression since none of the actual transfers in this category were to government enterprises in centrally planned economies.

The hypotheses are to some extent borne out by the data, but the small sample size must counsel caution in the interpretation of these results.¹ In chemicals and petroleum, the results indicate that transfers to government enterprises, and transfers before first commercialisation, involve substantial extra costs. Furthermore, both N_i and P_i are significant in the machinery category, despite the small number of observations, yet they are insignificant in chemicals and petroleum refining, where there are more than twice as many degrees of freedom. Apparently, the level of host country development and the degree of diffusion of an innovation have no bearing on the international-domestic transfer cost differential in the chemicals and petroleum grouping. This calls for an explanation. The diffusion variable N_i is taken to indicate the degree to which the requisite skills are generally available. The statistical results suggest that the relevant skills for highly capital intensive industries, such as chemicals and petroleum refining, are more easily transferred internationally than are the requisite skills in the machinery category.² Furthermore, P_i was not significant in chemicals and petroleum refining, suggesting that costs of transfer are independent of the level of economic development in this category. This is consistent with speculation that international transfer is no more difficult than domestic transfer when the underlying technology is highly capital intensive. The perceived reluctance of multinational firms to adapt technology to suit the capital-labour endowments of less developed countries could well be rooted in the desire to avoid escalating transfer costs to unacceptable levels.

VIII. CONCLUSION

The resources required to transfer technology internationally are considerable. Accordingly, it is quite inappropriate to regard existing technology as something that can be made available to all at zero social cost. Furthermore, transfer costs vary considerably, especially according to the number of previous applications of the innovation, and how well the innovation is understood by the parties involved. It is equally inappropriate, therefore, to make sweeping generalisations about the process of technology transfer and the costs involved. For instance, technology transfer in chemicals and petroleum refining displayed relatively low transfer costs, presumably because it is possible to embody sophisticated process technology in capital equipment, which in turn facilitates the transfer process.

The analysis of the determinants of technology transfer costs provided some interesting findings with development implications. The success of the more experienced enterprises, indicated by lower transfer costs, points towards economic models which emphasise the accumulation of skills, rather than fixed

¹ If the second observation on D_i in the machinery category is excluded, and the regression results recomputed, the estimates of the coefficients exhibit considerable instability and the "goodness of fit" deteriorates. The estimated equation is

$$D_i = -4.96 - 0.66N_i + 0.003P_i \quad (n = 8, r^2 = 0.45).$$

(1.14) (2.40) (1.94)

These estimates are nevertheless significant at the 0.05 level for a one-tail test.

² This is consonant with the views expressed by several project managers in the chemical industry. It was asserted that technology could be transferred with equal facility to almost anywhere in the world, including less developed countries, assuming host government interference is held constant.

assets or capital, in facilitating the technology transfer process. This seems consonant with the findings of several economic historians (Rosenberg, 1970; Rawski, 1975).

The results also provide some managerial implications for the multinational firm. Consider the costs associated with separating production from development (Arditti, 1968). The results indicate that the international transfer of technology is most likely to be viable when production runs are long enough to allow second sourcing. The especially high cost of transfer before first application favours the development location, at least for production of initial units. However, transfer costs will be lowered once the first production run has been commenced, and international transfer then becomes more likely, a finding consistent with the product cycle model (Vernon, 1966). However, inter-industry differences are important, and the costs involved in separating first production from development did not prove to be an insurmountable transfer barrier for an important subset of the sample projects.

A second implication is that since transfer costs decline with each application of a given innovation, technology transfer is a decreasing cost activity. This can be advanced as an explanation for the specialisation often exhibited by engineering firms in the design and installation of particular turnkey plants,¹ a characteristic particularly noteworthy of the petrochemical industry.

A third set of managerial implications relate to the criteria which might be used for the selection of a joint venture or licensing partner to utilise the innovating firms' technology abroad. While the manufacturing experience, size, and R & D to sales ratio of the transferee were identified as statistically significant determinants of transfer costs for the sample, there was also evidence to suggest that, *ceteris paribus*, any firm moderately matured in these dimensions is a good candidate to absorb the technology at the minimum possible transfer cost. It is not clear, therefore, that super giant firms have any advantage in this respect over moderately sized firms. Nor is it clear that highly research intensive firms have more than a slight cost advantage in absorbing technology over firms with a minimal commitment to research and development activity. However, manufacturing experience is important, especially for transferring machinery technology. In addition, there is evidence that transfers to governments in centrally planned economies involve substantial extra costs, perhaps because of high documentation requirements, or differences in language and managerial procedures.

Technology transfer by multinational firms is clearly a complex matter. Collection and analysis of proprietary data has provided some helpful insights. Few issues have been settled although many have been raised. Further analytic research and more extensive data collection is required if our understanding of international technology transfer is to be improved.

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¹ Turnkey plants generally embody state-of-the-art technology.

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