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TECHNOLOGY TRANSFERS TO DEVELOPING COUNTRIES THROUGH CONSULTING ENGINEERS: A MODEL AND EMPIRICAL OBSERVATIONS FROM CANADA

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I. INTRODUCTION

THIS paper analyzes the role and performance of consulting engineering and design organizations (CEDOs)[1] in transferring technologies to recipients in less developed countries (LDCs). It uses a learning model of technology transfer to explain the allocation of CEDO resources and to evaluate their effectiveness for the transmission of knowledge. Although the nature of this model is heuristic and excludes rigorous testing, due to the difficulty of quantifying levels of knowledge, some empirical evidence from a survey of the Canadian consulting engineering (CE) sector is included. The survey was carried out by help of a questionnaire returned by thirty-nine firms which had done business in LDCs, as well as by interviews with industry officials in ten of these firms.

The viewpoint taken in this study is one of economic development in that it considers the growth of technological knowledge as a major developmental objective. True technology transfers are regarded as means to achieve this goal; but whether CEDOs of the more developed countries (MDCs) are contributing in their activities to the development of technological capabilities in LDCs is the major question examined in this study. Since CEDOs typically gather and "package" technical information which they transmit in form of various services, they can be expected to play a major role in international technology transfers. The empirical evidence obtained from Canadian CEDOs suggests, however, that their actual contribution to the growth of technological capabilities in LDCs falls short of their potential. The reasons for this failure are seen in the lack of incentives to provide training and in the organization of contracts oriented toward the efficient completion of investment projects.

After a short review of the literature concerning technology transfers and

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[1] The appellation "consulting engineering and design organization" (CEDO) is adopted here from various studies related to the Science and Technology Policy Instrument Project of the International Development Research Centre [8].

learning models the third section describes the nature and activities of CEDOs. The learning model of knowledge acquisition and transfer is proposed in the fourth section. This is followed by an extension of the learning model which deals with the ability of the CE sector to stimulate industrial development. The sixth section evaluates the likelihood of closing the technological gap. The problem of transferring inappropriate technologies is addressed in the seventh section and the evidence from Canadian companies is summarized in the eighth. Some policy conclusions are drawn in the final section.

II. TECHNOLOGY TRANSFER AS A LEARNING PROCESS

Whether technology transfer leads to technological advance and economic development in LDCs has been debated at length in the socioeconomic literature. The concept of technology transfer has been used by various authors to describe quite different events. Most writers have focused on the diffusion of innovations from the innovator to users[2] (domestic or international); others have focused on knowledge transfer through manpower training, irrespective of the newness or proprietary nature of the knowledge.[3] Within the first group of writers some have been concerned with the acquisition of manufacturing rights and patents,[4] others more with the costs of alternative transfer arrangements [23]. Again, other authors have described technology transfer as an instrument of neocolonialism and exploitation.[5] The common denominator of most approaches to the phenomenon (with the exception of the neo-Marxist and *dependencia* schools of thought) is the transmission of knowledge. A dichotomy of thought seems to be developing according to which technology transfer is understood as either the simple acquisition of product/process specifications and manufacturing rights of an innovation, which is frequent in intra-country or international transfers among industrialized countries, or as the transmission of generic and usually nonproprietary engineering and management know-how to individuals and companies in LDCs. Which one of these two interpretations is most relevant in a given situation depends on the absorptive capacity of the recipient firm as well as on the newness and the proprietary nature of the technology to be transferred.

The literature on technology transfers is abundant. A recent bibliography lists more than 2,000 books and articles [16]. Most of these are either case studies or descriptive studies of specific aspects. Very few studies have analyzed technology transfer by constructing theoretical models, and to our knowledge, none has so far set out to test such a model. The fundamental problem and obstacle to such an endeavor is the definition and measurement of the stocks and flows of knowledge. Among earlier writers on the subject Verdoorn discussed learning curves in an economic context [26] and Lundberg described a learning process known as "Horndal" effect [11]. Arrow developed the concept of "learning-by-

[2] See for instance [2] [3] [13] [5].
[3] For instance [18] [21] [19].
[4] For instance [24] [25].
[5] For instance [17] or in a more liberal tradition [6] [22].

doing" within the framework of an economic model in which learning is limited to the capital-goods industry [1]. Kmenta suggested several specifications of the learning process and concentrated on the technological gap [10]. More recently, Findlay constructed a dynamic model of technology transfers to LDCs, in which the evolution of the technology gap is dependent on its original size and on the dominance of foreign over domestic capital stock [4].

In the present study technology transfer is defined as the transmission of technical knowledge through commercial contracts involving the provision of goods and services. Included in this definition of technology transfer are many types of contracts ranging from the delivery of equipment and the acquisition of production rights to the training of persons and the temporary provision of management with the transfer of responsibility. Complete technology transfers are therefore package deals including a whole variety of goods and services. Some contracts usually referred to as technology transfers, such as licensing or turnkey contracts, are in the sense of the above definition only partial technology transfers or elements of such transfers, since the actual transmission of technological knowledge may be minimal. It is also clear that complete technology transfers are longer-term processes, the number of years required depending on the complexity of the technology and the technological capabilities of the transferee.

Consulting engineering firms are potentially transferrers of technology since they typically render most of the services required for technology transfers, especially the study, planning, management, and execution of projects involving technology. The transmission of knowledge is viewed in the context of the CE industry as a learning process that takes place in both LDCs and MDCs. MDC-CEDOs simultaneously absorb and transmit knowledge thus learning from the execution of projects. LDC-CEDOs basically do the same, but with more emphasis on absorption since they are part of an infant industry.

The particular role of the CEDOs in international transfers of technology lies in the very nature of consulting activity. Consulting requires continuous growth of the knowledge base which occurs through learning from various outside sources as well as from own (corporate) experience. The experience of CEDOs consists of both project execution and knowledge transmission to technology users. The production process of CEDOs may be described as joint production for customers' needs and for own investment. Their learning process can be understood as a variation about Arrow's theme of learning by doing.

III. THE CE INDUSTRY AND ITS ACTIVITIES

Although much of what this paper argues may also apply to consultants in science, politics, or law, a somewhat narrower focus is necessary in order to analyze the activities of the industry with more concrete details. In terms of the nature of its activities and corporate affiliation, the industry is heterogeneous. Its principal members are:[6]

[6] A similar classification is suggested in [14].

(a) independent consulting engineers (personal or incorporated),
(b) engineering consultants and contractors integrated in the same firm,
(c) CE departments affiliated with manufacturing, mining, or utility companies,
(d) engineering consultants affiliated with management consultants.

Excluded from the industry definition are pure management consultants, accountants, marketing and advertizing specialists. The differences between firms are important with regard to their capacity for technology transfer. CEDOs that are part of manufacturing, mining, and utility companies [category (c)] have more direct access to proprietary technologies than independent CEDOs. On the other hand, they are possibly more limited in their choice of innovative techniques since they represent the interests of their parent companies. The independence of pure CEDOs [category (a)] is probably one of the industry's comparative advantages vis-à-vis equipment suppliers and other technology-generating or technology-owning firms because CEDOs are able to choose technologies from a larger set of alternatives and may therefore meet more closely the customers' needs.

The definition of CEDOs in LDCs is necessarily loose as many LDCs hardly possess such an industry. When formal engineering consulting firms are either not existing or of little importance, we include engineers of other industries in the group of transferees. This simplification is made only for modelling convenience in order to deal with a single industry for the two groups of countries. At a later stage we shall argue that CEDOs are known to originate from the consulting experience of individuals or departments in various other types of firms.

A. *Project Types and Stages*

CEDOs provide a very large variety of services in different kinds of "packages." The major service categories are:
(a) feasibility and market studies,
(b) engineering and design,
(c) procurement,
(d) project management and execution,
(e) start-up and commissioning,
(f) manpower training.

If all these services, or those under (b) to (e), are provided in one contract, the "package" is usually referred to as the turnkey mode. It shifts the risk of project failure to the technology supplier, which may be the reason for its popularity from the LDC standpoint. It may also involve only minimal knowledge transfer, unless the turnkey contract includes explicitly a management contract combined with a manpower training scheme for higher level manpower. At the other end of the spectrum of technology "packages" is the self-administration mode in which, as Kamenetzky defines, the investor himself or in collaboration with a third party (such as an engineering firm) buys the different pieces of equipment and technological knowledge separately and then coordinates their integration [9]. Whether complete "packages" or single services suit better the needs of recipient firms depends on the state of technological and managerial

TABLE I

ELEMENTS OF ENGINEERING AND MANAGEMENT KNOW-HOW TRANSFERRED THROUGH CE SERVICES ACCORDING TO PROJECT TYPES AND STAGES

Project Type or Stage	CE Services Embodying Elements of Knowledge	Elements of Knowledge Transferred through CE Services
(Pre-) feasibility	Feasibility and market studies	Knowledge of markets, technologies, benefits and costs of specific activities (industries, public projects) for further decision making
Engineering and design	Blueprints and design criteria	Detailed technical information required for implementing production processes
Procurement	Ordering of material, equipment and various services	Market and technical information about materials and equipment as provided by specific suppliers
Management and execution	Provision of management or construction services	Information about total installation, its operation and maintenance, scheduling critical paths, costs, skill requirements and personnel
Manpower training	Provision of training	Knowledge of all stages provided so as to enable the recipients to function independently
Start-up and commissioning	Technical demonstration and certification	Knowledge concerning quality and safety standards, host country and international regulations, operating and maintenance procedures, trouble shooting

development of the recipient firm and its society. Maturing countries will increasingly choose "un-packaged" modes as they possess more skilled manpower needed for self-management.

B. *Elements of Knowledge and Modes of Transmission*

The technological and management knowledge transferred may be embodied in documents (including blueprints), in physical capital (equipment, parts, materials), or in human minds. Accordingly, there are numerous forms of transmission of such information. Some of the embodiments of information are shown in Table I for the principal types and phases of projects. The table does not include the transmission of knowledge embodied in physical capital, because the hardware emanates from different suppliers. CEDOs mainly contract services and these are delivered either as documents or as manpower services. Feasibility studies and design fall into the former category while procurement, commissioning, start-up, and training fall into the latter.

In addition to the typical engineering consulting services described above, CEDOs are often expected to share the know-how that enables them to provide these services. The only project type focusing specifically on the transmission of such know-how is the training contract. Among Canadian CEDOs there exists a small group of firms that specialize in manpower training. It was also reported in interviews that the World Bank and other international funding agencies increasingly encourage the inclusion of formal training into consultant contracts. Often training is combined with management contracts. However, the transmission of engineering know-how to LDCs is not limited to formal training. It may also occur whenever individuals from LDCs and MDCs collaborate in the execution of projects. In such joint ventures corporate ownership, the distribution of tasks and subcontracts, as well as the whole organization of projects, are of crucial influence to the effectiveness of knowledge transfers. Since the organization of projects often lies within the responsibilities of funding agencies, the effectiveness of knowledge transfers is partially determined outside the technology transmitting and receiving firms.

IV. CEDOs IN A LEARNING MODEL OF TECHNOLOGY TRANSFER

The work of consulting engineers and that of CEDOs was earlier described as collecting, packaging, and transmitting information. By packaging information, we mean the use of specific knowledge for producing marketable output, such as studies, design, management, and training, which are the major services rendered by CEDOs. The provision of these services always implies the transmission of some elements of knowledge. The transmission of knowledge can take the following forms:

(a) formal instruction through training courses,
(b) on-the-job training,
(c) collaborative management with the provision of shifting responsibilities from foreigners to nationals (an upper-level form of on-the-job training),
(d) the delivery of documents or computer software,
(e) the delivery of different kinds of hardware (equipment, intermediate goods, or materials).

While the first three of these activities directly involve learning processes, the latter two only provide information that can subsequently be absorbed. Therefore their learning intensity is much smaller than that of the former. Since both, transferrers and transferees continuously acquire new technological knowledge, due to rapid technical change, we shall consider first the acquisition of knowledge, before examining its transmission.

A. *Knowledge Acquisition*

Technological knowledge, more than physical capital or unqualified manpower, is the prime factor of production of the CE industry. In the present context it is therefore appropriate to describe knowledge as a separate production factor although it can hardly be dissociated from the factors, labor and capital, when is come to measurement. The acquisition of technical knowledge by CEDOs can be modelled as a learning process in which the firm increases its major productive factor. It is interesting to note that knowledge plays a different role in the production of services by CEDOs than the factors, capital and labor. Rather than being consumed in the production process, as capital and labor are, it accumulates. Knowledge is at the same time an input and an output in the production process. Therefore, the accumulation of knowledge does not cause an investment outlay in the same sense as the accumulation of physical capital, i.e., by foregoing output. Some activities, such as research and training seminars, require primary inputs for the generation and accumulation of knowledge, but production itself also generates knowledge. In the case of CEDOs we refer to this as "learning by consulting" in analogy to Arrow's model of learning by doing.[7] The learning function can be written as

$$\dot{H} = F(A, X),$$

or, assuming a neoclassical functional form

$$\dot{H} = Ae^{gt} \cdot X^{a},$$

where

$\dot{H}$ = the increase per time period of technological knowledge in a given CEDO or the CE industry,
A = the level of technological capabilities and general education in the rest of the economy,
g = the rate of growth of A, assumed to be autonomous,
t = an index of time,
X = a measure of CE activity, for instance, man-hours of engineers and other professionals,
a = elasticity of knowledge increase.

The variable A captures the contribution to CEDO learning of the technical and educational environment in which the firm operates. The interaction between the firm and its environment may take various forms: (a) hiring of new employees and consultants who bring into the firm their knowledge and skills acquired in educational and training institutions and in other firms; (b) contacts with other firms, especially with innovating or technology-generating or technology-using firms; (c) subscription to and use of professional journals and other information sources; (d) training sessions and seminars provided by the firm to its employees, etc. Since the time spent on contracts and the time spent on knowledge updating are difficult to separate, we are including in the learning function a single input variable representing CEDO time which interacts with A in a way similar to the relationship between factors of production and technical

[7] The analogy with Arrow [1] is not complete as Arrow's "doing" refers to investment rather than production.

change in a production function. This simplification may be justified by the lack of recorded data in this area as well as by the heuristic nature of this model. The learning process may then be described as an interactive process involving the CEDO's time spent on consulting and information gathering, and the level of technological capabilities available in the firms' business environment.

In alternative formulations one could either build a time lag into the learning function as suggested by Kmenta [10] or let the educational effect of each project decrease exponentially in time, as suggested in an early study by Haavelmo.[8] For the purpose of clarity the learning function is kept simple here, however, in order to extend it further as a transfer model. The level of accumulated technological knowledge in the firm at time t can be written as

$$H_t = H_0 + \sum_t A e^{gt} X^a.$$

H_t is the stock of the major productive factor of CEDOs which, together with X, produces CEDO services. This relationship is not considered here.

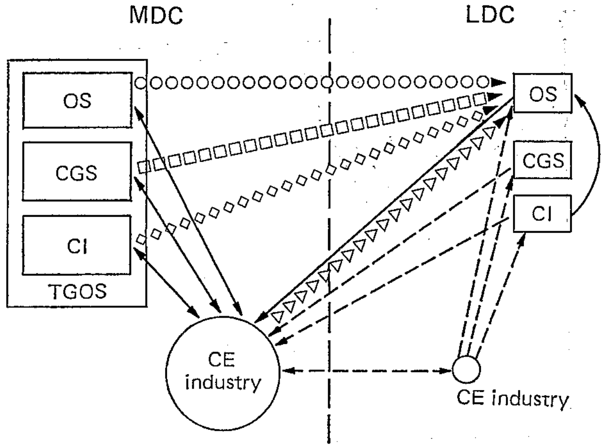
B. *Knowledge Transfer*

The general model of knowledge arquisition discussed so far can be extended to the transfer from MDC-CEDOs to LDC recipients. This requires two modifications. First, the transferee is not necessarily a CEDO, but a firm belonging possibly to any sector of the economy. If the transfer involves the activities of a developing country CEDO, then the recipient LDC is likely to obtain additional benefits through the special role of CEDOs in industrialization discussed in Section V. Second, while in the knowledge acquisition model only the firm's own activity level and an exogenous technology variable determine the addition to knowledge, the transfer model explains the specific role of the technology transferring foreign CEDO in the learning function of the LDC recipient firm. This is of course a simplification since the information flows in actual technology transfers include also other firms than CEDOs as transferrers on the MDC side.

In order to clarify the process of knowledge transmission from various industrialized-country (MDC) firms to a less-developed-country (LDC) firm consider Figure 1 showing the goods, service, and information flows in projects involving the services of CEDOs. The MDC-CEDO collects technical information from the technology-generating/owning sectors (TGOS) such as the "operational" sectors (OS) like mining, manufacturing, utilities, or public works; the capital-goods sector (CGS); and the construction industry (CI). The collected technical information or knowledge is "packaged" by the CEDO into typical CE services like studies, design and engineering, management, procurement, commissioning, and training. In providing these services to LDC recipient firms the MDC-CEDO contributes to the flow of knowledge to LDCs. This does not exclude that some elements of technical knowledge are flowing directly from the original owners

[8] Haavelmo, T., *A Study in the Theory of Economic Evolution* (Amsterdam: North-Holland Publishing Co., 1954), as referred to by Arrow [1].

Fig. 1 Goods, Service, and Information Flows in Projects Involving CEDOs

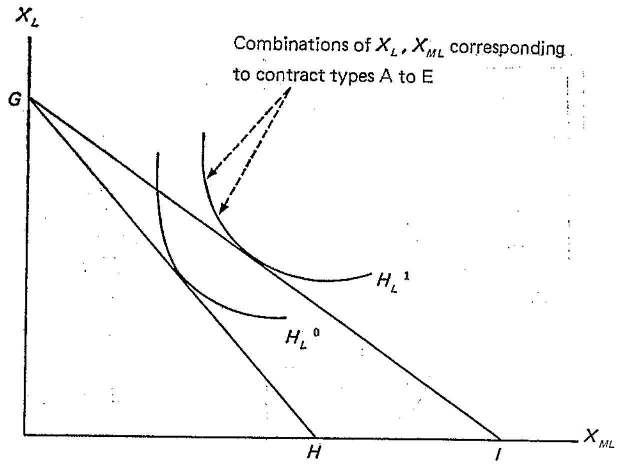


Notes: 1. Agents
OS = "operational" sector (mining, manufacturing, utilities, or public works); this sector is the ultimate recipient of technology for use in production,
CGS = equipment (capital goods) producing sectors,
CI = construction industry,
TGOS = technology generating/owing sector.
2. Goods and Service flows
□□□► plant equipment and parts.
○○○► the technology in a narrow sense (product and process specifications, engineering and design, user rights, etc.).
◇◇◇► construction services.
▷▷▷► typical CEDO services (pre-investment studies, design & engineering, management, training, etc.).
◄——► pure information flows (including procurement, and all information relating to the technology transferred).
◄---► any of the above information and service flows when LDC firms are involved.

to the recipients, especially the hardware incorporating knowledge, or construction services rendered directly by subcontracting construction companies, or even blueprints and other documents that may also be transmitted directly from technology-owning firms to the LDC recipients. Figure 1 also shows the service and information flows when CE services are involved on the recipient LDC side.

In analogy to the knowledge acquisition model, the learning function of LDC recipient firms may be written as follows:

Fig. 2. Learning Function of LDC Firms Combining MDC CE Services (X_{ML}) and Local Engineering Services (X_L)



$$\dot{H}_L = A_L e^{g_L t} \cdot X_L^{a_L} \cdot X_{ML}^{b_L},$$

where

$\dot{H}_L$ = the recipient firm's increase of technological knowledge,
A_L = the general level of education in the recipient country,
g_L = the growth rate of A_L (autonomous),
X_L = a measure of own engineering services provided by the recipient firm in conjunction with X_{ML},
X_{ML} = engineering services provided by the MDC-CEDO or any other MDC firm participating in the transfer,
a_L = elasticity of learning from own (LDC recipient) experience,
b_L = elasticity of learning from the transferrers or from being trained.

The parameters a_L and b_L measure the acceleration of knowledge accumulation as a result of jointly executed development projects.

The transfer function is depicted in Figure 2 where the familiar isoquants in X_L, X_{ML} space represent constant levels of increase in technological capabilities of the recipient firm, and the slopes of *GH* and *GI* are the price ratios of MDC CE services to LDC technical manpower inputs for two different prices of X_{ML}.

It follows from the assumed shape of the learning isoquants that the same increase in technological capabilities can be obtained by combining either large amounts of LDC engineering skills with small amounts of MDC engineering input, or the reverse proportions. The two inputs are neither perfect substitutes nor perfect complements. Some of each is necessary for learning to occur.

This hypothesis is based on the premise that some technological knowledge relevant for the advancement of the recipient firms in LDCs is always imported, at least in projects involving MDC-CEDOs, and that collaboration is necessary for the acquisition of such knowledge. Although not testable in a quantitive manner the hypothesis of substitutability is one of the major questions examined using the empirical evidence of Canadian CEDOs. The implication of wide-ranging substitutability is that prices of local (LDC) and foreign (MDC) engineering input are likely to influence enterprises in their choice of contractual arrangements involving technology transfers.

If line *GH* in Figure 2 reflects the market price of foreign CE services and *GI* a lower price subsidized by foreign aid, it would be expected that firms maximizing the increase of technical know-how choose relatively more foreign engineering services than they would do without foreign financial assistance. Whether engineering capabilities increase proportionately with the increase of engineering input of the two types depends on the marginal efficiency of these inputs to generate knowledge increases.

It is also possible that firms allocate own and foreign engineering input in ways that do not maximize the growth of technical capabilities. This is quite plausible because maximizing profits in joint projects does not imply maximizing the firms' knowledge base. It is therefore relevant to ask whether technology recipient firms tend to maximize the growth of their technological capabilities or whether they tend to forgo this opportunity in favor, of immediate financial benefits. This problem is a conflict between short-run and longer-run goals. The empirical evidence has suggested that among recipients of technology government officials are more keen on training than private sector firms.

In this discussion we have so far not stated explicitly how the technology-receiving firm typically allocates varying amounts of foreign and own engineering input. Three factors influence the way foreign and own services are combined, (a) the nature of projects, (b) the kind of CE services contracted and subcontracted, and (c) the project organization.

(a) Nature of projects

The nature of projects involving CE services varies with the field of activity as well as with the project type or stage. Fields of activity covered by CEDOs range from rural development to tertiary sector activities. Literally all sectors of the economy can be involved. Project types or stages as listed in Table I vary substantially with respect to the combination of local and foreign CE services. Feasibility studies for instance, provide relatively less opportunity for collaboration than design and project execution.

(b) Kinds of CE services

Within each type or stage of project there is room for various services and role allocations to local and foreign firms. This allocation depends mainly on how advanced and how specialized local firms are and how much foreign assistance they need. With regard to the transmission of knowledge CE services can range from formal training to the simple delivery of goods and services as shown above.

(c) Project organization

What we refer to as project organization is the distribution of tasks between local and foreign services which may take the form of the following contractual arrangements:

A. The project is managed and executed by LDC subsidiaries of MDC-CEDOs.
B. The project is managed by an independent LDC-CEDO which subcontracts specific services to MDC firms, including CEDOs.
C. The project is executed by a consortium of MDC and LDC firms with joint responsibilities of management.
D. The project is managed by an MDC-CEDO which subcontracts various services to LDC firms, including CEDOs.
E. The project is managed and executed by MDC-CEDOs hiring local engineers and professionals.
F. The project is managed and executed totally by MDC firms without any local (LDC) contribution.

These six contract types are listed in declining order of LDC participation, assuming that the subsidiaries of MDC-CEDOs (type A) are locally incorporated and employ mainly local engineers. Type F contracts, on the other hand, produce only minimal knowledge transfers in the sense of the present model.

It is likely that the different types of contract are not equally efficient in transferring technological knowledge. While some of the combinations of X_L and X_{ML} corresponding to these contract types may lie on the same $\dot{H}_L$ isoquant, others may lie further away from the origin. The unit isoquant, which is the envelope of all X_L/X_{ML} combinations yielding the same increase of technological know-how, is somewhat hypothetical because some contract forms, while being efficient, may be feasible only with larger amounts of X_L or X_{ML}. These considerations are in strict analogy to the theory of production. The question that has been examined here on the basis of empirical evidence is which ones of the contract types provide technological learning more efficiently and which ones are chosen under different sets of incentives. It is worthwhile considering the learning efficiency of the five contract types on a priori grounds.

In projects managed and executed by LDC subsidiaries of MDC-CEDOs (type A) the flow of technology is potentially most important since subsidiaries are provided with the parent firms' technological knowledge. Local managers, engineers, and technicians have the greatest possibility for being trained and for receiving the maximum of information MDC-CEDOs are willing to release. Although the profit motive would seem to guarantee this result, political considerations, especially the threat of nationalization, may contribute to reduced benefits of transnational affiliates. The assumption may also be overly optimistic if the subsidiary operates in a foreign "enclave" and the foreign technology is not assimilated.

The potential for knowledge transfer is likely to be reduced in consortia between MDC-CEDOs and LDC-CEDOs (type B) as the information transmission is typically limited to the immediate needs of the project. But the collaborative execution of similar tasks still offers a strong potential for learning.

When independent LDC-CEDOs are in charge of projects they are likely to learn mainly from own experience (type C). Their access to new technological and managerial know-how may take the form of subcontracting of specific services to MDC firms. However, this contract type prevails in countries that have already more advanced technological capabilities. Given the knowledge and managerial abilities of the project-managing LDC firms, they may put more emphasis on the acquisition of know-how.

If MDC-CEDOs are in charge of a project and rely on local firms only for specific services (type D) the odds are that the transfer of knowledge to executing firms, especially competing CEDOs, is weak, unless specific training contracts are part of the project. Still less emphasis lies on the transfer of knowledge when MDC-CEDOs execute projects using only their own resources, with the exception of hiring local labor for unskilled tasks (type F). In type E contracts, however, there is much potential for knowledge transfer since skilled persons may be trained in-the-job.

V. CEDOs AS ENGINES OF DEVELOPMENT

CEDOs are not only potential transferrers of technology but may also act as catalysts in the process of industrialization.[9] They can play this additional role if they are locally incorporated and managed and if they pursue local interests by using maximally local resources in subcontracts for development projects. Foreign (MDC) CEDOs can also enhance development if they contribute to the growth of a domestic (LDC) CE sector, for instance by establishing LDC subsidiaries or by entering into joint ventures. Their role can be unfavorable for development if in executing development projects they fail to transfer know-how and prevent local firms from developing technical and management skills.

A recent inquiry into the origins and growth of CEDOs in several LDCs suggests that there are six major patterns that differ in terms of the nature of the founding agent transforming later into consulting firms [12]. Malhotra reports that CEDOs typically originate from (a) architectural, construction, and public works organizations, (b) R & D labs, (c) the engineering departments of "operating" organizations, (d) sales departments of equipment-supplying firms, (e) subsidiaries of transnational corporations, or (f) they are founded spontaneously, often by intervention of governments. The empirical survey of the present study provided also evidence of some cases in which Canadian CEDOs have been instrumental in the establishment or further development of a domestic (LDC) CE industry. On the whole, however, local initiatives seem to be more often at the origin of CEDO activities than foreign CEDOs.[10]

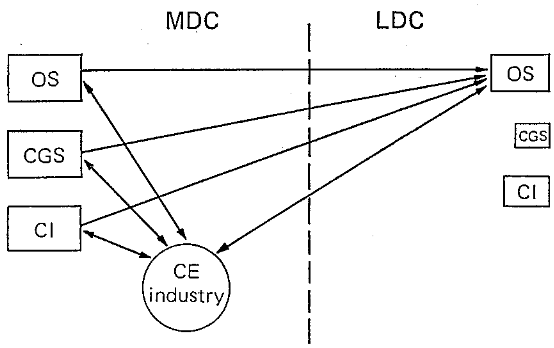
The potential role of CEDOs, both foreign and domestic ones, in the development of engineering capabilities and in the process of industrialization is shown in the three-phase sequence of Figure 3 which uses the same framework and symbols as Figure 1.

In the early stages of development there exists a triangular relationship between

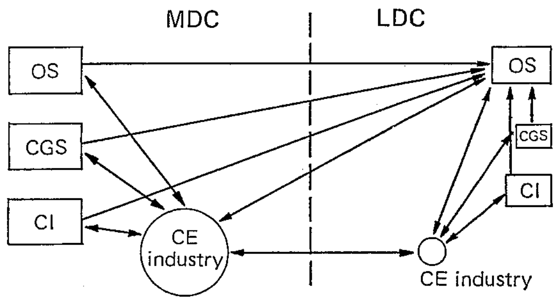
[9] This point was first made by Roberts [13].
[10] The full report on this survey is available as [20].

Fig. 3. Information Flows (Embodied and Disembodied Ones) in CEDO Contracts: Three Phases in the Development of the CE Industry in LDCs

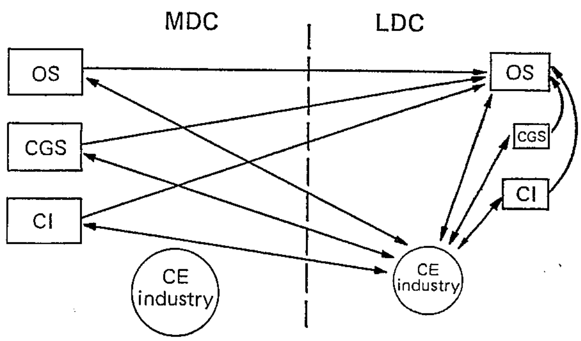
a. Phase I: Total dependence on MDC firms (triangular relationship, type E contracts)



b. Phase II: Foreign and local CEDOs provide services; local capital goods and construction services are increasingly used (rectangular relationship, type D contracts)



c. Phase III: Local CEDOs are project managers (triangular relationship, type B contracts)



the foreign generators/owners of technology, foreign CEDOs and the LDC recipients or users of technology. This relationship is shown in Figure 3a and reflects the types E or F of project organization. It is frequently found in LDCs with only small construction and capital-goods industries and no CE sector. The final recipient of CEDO services and technology is a firm in the operational sector of an LDC, for instance a new mining, manufacturing, or utility establishment. The technology originates in the operational sector of an MDC, the equipment is supplied by the MDC capital goods sector and even construction is executed by MDC contractors, while an MDC-CEDO provides overall management, pre-investment studies, some engineering and design, procurement, and some training. These service flows are embodied information flows in the sense that information is transmitted in conjunction with the delivery of hardware and the provision of various services. The link between the CEDO and the technology-generating/owing sector (TGOS), on the other hand, is a pure two-directional information link by which the CEDO receives information about technology and the TGOS receives information about the needs of the recipient (LDC-OS). The reverse information flow from LDC-OS to the CEDO is of great importance for the CEDO accumulating knowledge about how to apply and adapt technology in the LDC environment.

When, over time, the LDC CE industry as well as the operational sector, capital-goods industry and construction develop, their contributions to development projects typically increase. As a consequence, the formerly triangular relationship becomes a rectangular one by integrating local CEDOs and local subcontractors (Figure 3b corresponding to types C and D). In the final stage of such development (Figure 3c) the relationship may become again triangular, but in a new order: LDC-CEDOs are now managing projects and choosing technologies. This situation corresponds to type B, the self-management mode. New technologies may still be imported from foreign firms but the project management lies entirely in the hands of domestic CEDOs and much of the other services are provided by domestic subcontractors. The LDC-CEDOs may eventually even export engineering services and thereby participate in the re-transfer of technologies, as is presently the case, of Brazilian, Indian, and other newly industrializing countries' (NICs') CEDOs.

The importance for LDCs of the development described above is that MDC-CEDOs not only have the potential to transfer technologies but, by doing this, act as catalysts in generating and enhancing the growth of the CE industry which in turn, stimulates industrialization by increasingly using local resources in development projects. They are therefore potential engines of technological development.

VI. THE TECHNOLOGICAL GAP

With the arithmetic formulation of the model developed above, it is possible to predict how technology transfer by engineering consultants affects the technological gap. Several contributions in the literature on technology-oriented development have focused on this gap. An interesting question is whether the gap is widening or whether technology transfers are contributing to narrow the gap. The industries involved in the transfer of technologies, in particular firms in MDCs, are also concerned with the question whether a narrowing gap would diminish their competitivity and future prospects.

The technological gap between the MDC and LDC engineering industries may be described as the difference in accumulated technical know-how $(H_M - H_L)$. The gap, whatever its original size, narrows if

$$\dot{H}_M < \dot{H}_L,$$

or

$$A_M e^{gt} \cdot X_M{}^{a_M} < A_L e^{g_L t} \cdot X_L{}^{a_L} \cdot X_{ML}{}^{b_L},$$

where the subscripts M and L refer to MDCs and LDCs respectively. In order to derive a tentative prediction about the likely development of this gap let us assume, for simplicity, that a given project in a developing country is executed jointly by two CEDOs, one from an MDC (M-CEDO) and one from the LDC recipient (L-CEDO), implying that L-CEDO represents at the same time consulting engineers and the technology recipients. The total engineering work is shared by the two partners such that $X_M = X_{ML}$ and the ratio $c = X_L / X_{ML}$ is smaller than one, assuming that:

$c<1$ if the LDC is in an early stage and
$c>1$ if the LDC is in an advanced stage of engineering development.

The environmental condition reflecting the general educational standards in both countries can be assumed to be:

$$A_M > A_L.$$

In addition we shall assume that general education levels grow at the same rate:

$$g_M = g_L.$$

The condition for the project to contribute to the narrowing of the technological gap can then be written as:

$$\frac{A_M}{A_L} \cdot X_M{}^{a_M} < (cX_M)^{a_L} \cdot X_M{}^{b_L},$$

or

$$\frac{A_M}{A_L} c^{a_L} < X_M{}^{a_L + b_L - a_M}.$$

Since $A_M / A_L > 1$ and $c^{a_L} < 1$ during the early stage of development, the left-hand side is unequivocally larger than one. It follows that the gap can narrow only if

$$a_L + b_L > a_M.$$

The sum of L-CEDO elasticities of learning from own experience (a_L) and from being trained (b_L) must exceed the M-CEDO learning elasticity. One of our empirical findings reported in Section VIII is that M-CEDOs seem to learn more from project execution in LDCs then the recipient firms learn from the former (i.e., $a_M > b_L$), unless the M-CEDO provides training for the L-CEDO engineers, in which case b_L is likely to exceed a_M. This finding implies that in many development projects involving M-CEDOs the technology gap is likely to widen, especially if L-CEDO participation in the projects is small ($c \ll 1$) or if the general educational level in the recipient country is low ($A_L \ll A_M$).

If, on the other hand, the L-CEDO has reached already a high level of technical know-how and participates in the project in a managing position so that $c>1$, it would be very unlikely for the gap to widen. One may argue therefore that in the early stages of technological development, when LDC projects are typically completed by foreign firms without much participation of own engineers and with no or only minimal training provided, the gap has a tendency to widen, and that only after a certain threshold of engineering development is passed the gap is likely to narrow.

The transfer of knowledge with the consequent narrowing of the technology gap raises the possibility that firms breed their future competitors. Therefore the true transfer of know-how has been considered a danger to the industry in technology-exporting countries. Strategies such as the "retention of core technology as a hedge against future competition" have been observed to be followed by various firms [2].

For the more advanced stages of CEDO development in LDCs the present model suggests that the technological capabilities of LDCs may grow so strongly that the gap is not only narrowing but fully eliminated. This characteristic distinguishes the model clearly from other models in which the gap is the driving force of progress in LDCs.[11] Although the possibility of disappearance or reversal of the gap is remote, given the likely parameter values, the model provides no argument against the fear of growing international competition and a slowdown in the release of new technologies as a reaction.

However, other theoretical arguments based on empirical evidence mitigate against the view that a narrowing gap may reduce the MDCs' share in CEDO contracts. Recent studies in international trade have shown that under trade liberalization among high income countries the strong increase in trade relations was mainly attributable to intra-industry trade rather than to inter-industry trade.[12] This is the result of comparative advantage developing in specific types of product rather than in whole industries. Similarly, it can be expected that engineering consulting firms preserve or gain comparative advantage in specific areas based on MDC technological change. They are likely to specialize in areas where more advanced technologies are used.

[11] For instance Findlay [4] who refers to it as the Veblen-Gerschenkron hypothesis.

[12] See [7].

VII. PROBLEMS IN TRANSFERRING TECHNOLOGY

Unfortunately the role of CEDOs in the above model is somewhat idealized. The main problems preventing CEDOs from playing the role ascribed to them are the weakness of true knowledge transfer and the risk of transferring inappropriate technologies. The actual transmission of knowledge is often weak because most CEDO contracts are concluded for the execution of projects in which training is not a priority. This situation is likely to change as LDCs become more aware of their needs for technological and managerial know-how.

In the above model specification the accumulation of technological capabilities is cast into the conventional framework of economic rationality. Cost minimization would lead LDC-CEDOs to use more indigenous skills the lower is the cost of domestic (LDC) relative to foreign (MDC) engineering services. But since many development projects are funded or subsidized by foreign aid the relative cost of foreign engineering services is lowered artificially.

Consequently, the allocation of foreign versus domestic skills in aid-funded projects is biased in favor of foreign skills. If the prices of both inputs, P_{ML} and P_L, are understood as shadow prices reflecting the true social opportunity cost as well as the major development goals, then the same framework can be used to determine the socially optimal allocation of resources for developing technological capabilities.

One of the most complex questions in investigating technology transfers is the one concerning the appropriateness of the technologies transferred. Appropriateness is understood here in the sense of conveying net social benefits rather than only net private benefits. In other words, the evaluation of the technologies transferred has to take into consideration also external effects, the scarcity or abundance of resources, and the socioeconomic goals of the receiving country. Social cost-benefit analysis of some kind is therefore necessary to determine the appropriateness of technologies being transferred. The difficulty here is that the analysis requires extensive sets of data that are not easily available. In addition, neither the recipients (investing firms or governments) nor CEDOs generally have the know-how required for social cost-benefit analysis. Several CEDO officials stated that they simply transfer the technologies requested by their clients. There is no doubt, however, that well-documented research into the needs of investors may identify technologies that are different and more appropriate to the social needs of LDC recipients than those requested without thorough investigations.

VIII. EMPIRICAL OBSERVATIONS FROM CANADIAN CEDOs

The empirical investigation for this study proceeded by interviews and a questionnaire which was sent out to 100 and returned by 39 of the largest and most export-experienced CEDOs. The respondents included not only independent CEDOs but also CEDOs affiliated with manufacturing and service enterprises.

The inquiry revealed that some of the affiliated CEDOs are major competitors in terms of size and competitive strength. It was found that their competitive edge over independent CEDOs results from three factors, direct access to the technology of the parent organization, a greater role of R & D, and more resources being devoted to manpower training.

Most of the larger Canadian CEDOs surveyed claimed to have some experience with technology transfers to developing countries. However, their main preoccupation lies in completing projects on time and within budget, whereas the transmission of knowledge is usually only a by-product. The nature of projects and the areas of specialization are such that proprietary technology plays only a minor role. Most firms are mainly involved in the area of generic and non-proprietary technology in which the transfer consists essentially of the transmission of knowledge through formal or informal manpower training. Therefore technology transfers in the narrower sense, i.e., the provision of manufacturing rights for new and proprietary technology are infrequent.

These characteristics of Canadian CEDOs have implications for their acquisition of information in view of maintaining and updating their knowledge base. Firms rely nearly exclusively on in-house resources and publicly available information sources. Priviledged access to and subcontracts with innovating firms for the purpose of acquiring new technology are rare. The only more frequently used external source of information is hiring of consultants. The respondents also indicated that they rely quite strongly on own R & D for updating their corporate knowledge, which is interpreted as evidence of adaptive research related to projects in new environments. The enquiry broadly confirmed our hypothesis that CEDOs derive much of their corporate knowledge and competitive strength from their own experience of executing projects, referred to as "learning by consulting."

As to the transmission of knowledge, the study found that only a small fraction (3 per cent in independent and 30 per cent in affiliated CEDOs) of their fee income is devoted to formal manpower training. In the majority of projects there are no incentives for training included in the contract. This is likely to be a consequence of dominating concern with physical over human capital formation on behalf of both clients and financing agencies. There is a trend, however, toward more emphasis on training and toward more LDC participation.

Project organization was found to play an important role in the transmission of knowledge because it affects the relationship between the transferrers and transferees of know-how. It seems that in transfers to recipients in countries with very limited technological capabilities the contract type most conducive to know-how transmission is project management by an MDC-CEDO employing LDC engineers and technicians and training them "on the job" in a one-to-one relationship. In more advanced LDCs the subcontracting model, or the one with project management by an LDC-CEDO, may be more efficient. In either of these contract types it is important to specify goals for the transfer of responsibility and performance criteria, in order to generate incentives for the trainer and trainee.

The observation that only a few combinations of MDC- and LDC-CEDO services seem to be efficient in know-how transmission means that the two inputs in the learning function are not widely substitutable. It also implies that small changes in their relative prices are not likely to change their allocation substantially. It was found that in recent years more projects of Canadian CEDOs in LDCs were financed by the clients and less by foreign aid (except for multilateral aid). This suggests that in the allocation of local (LDC) and foreign (MDC) engineering manpower the investors have faced increased costs of foreign resources. This may have led to increased demand for local participation in the execution and management of development projects.

Another area of expanding demand and the need for additional incentives is research on technological adaptation. The survey concluded that some adaptive research takes place in Canadian CEDOs and that most firms attribute at least some importance to it. Since the LDC recipients of technology are often not in the position to make socially optimal choices it seems necessary that CEDOs strengthen their capabilities of socioeconomic impact analysis as well as R & D on technological adaptation. The absence of sufficient information on the buyers' side suggests the possibility of market failure, so that public subsidization may be appropriate. On the other hand, subsidization may also lead to a non-optimal combination of foreign and domestic engineering services, to the detriment of learning. Canadian CEDO experience provides some evidence of subsidized projects without any knowledge transfer.

IX. CONCLUSION

The model of the engineering consulting industry presented in this paper suggests that an increased volume of development projects in LDCs enhances the industry's knowledge base in both the industrialized and the developing countries. In LDCs the execution of such projects can lead to the foundation of a CE industry. The newly formed CEDOs may be offsprings of foreign CEDOs or they may grow out of the engineering activities of other types of firms. Since the CE industry in the newly industrializing LDCs may advance more rapidly than in the MDCs when the knowledge transfer is optimally organized, its technological lag may diminish.

This conclusion is broadly supported by the views of industry officials. At present and in the near future the industry based in MDCs seems to face two major trends: increased competition on international markets due to the emergence of new competitors in LDCs, and an increased demand for knowledge transfers as opposed to the simple execution of projects by MDC-CEDOs. With increased government awareness and involvement the maturing LDCs will increasingly require the release of know-how rather than the purchase of turnkey type projects.

For industrialized countries' policies in the area of Third World cooperation this suggests that MDC governments should build more knowledge transfer arrangements into the grant or loan programs and thereby increase the flow of technological knowledge to LDCs. In order to meet the increased international competition in engineering consultancy MDC-CEDOs may have to invest more in the maintenance and improvement of their comparative advantage. This implies not only more marketing but also more R & D in order to make best use of the technological development in various sectors of the MDC economies. So-called high-technology applications are not necessarily inappropriate for the LDCs. Frontier technologies such as modern telecommunications and space technology, fiber optics, solar energy and other "soft" technologies, petroleum substitutes, and biotechnology may be such areas.

Government policies vis-à-vis CEDOs may also consider increased incentives for R & D expenditures. Although it is not well known how much R & D CEDOs actually undertake, it is in the nature of this industry as packagers and transmitters of knowledge to benefit from research. One area that seems to bear great potential benefits is research into the adaptation of new and well-known technologies to new environments, especially the socioeconomic environments of the developing countries.

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