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A QUANTITATIVE MODEL OF TECHNOLOGY TRANSFER AND TECHNOLOGICAL "CATCH-UP"

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Abstract

This article presents a quantitative model for the analysis of technological development and technology transfer. The rates of development of technological leaders and followers are expressed in terms of coupled equations. On the basis of this model, comparative development rates and the dynamics of the gap between leader and follower are analyzed. The usefulness of this approach is then demonstrated in the analysis of the development of mainframe computers in the U.S. and U.S.S.R., and the nature of the "technological gap" are assessed quantitatively.

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I. Introduction and Statement of the Problem

Technology and technological gaps between states are seen to be of fundamental importance in the second half of the 20th century. These gaps are perceived as the sources of international economic disparities and of differences in military power. Technology is a central focus of the dialogue between the advanced industrialized world (the North) and the industrializing countries (the South).[1] It is also seen as a major factor in the assessment of the military balance between the US and USSR. According to the dominant view, while the USSR may have deployed more weapons and men than the US, this imbalance is offset by American qualitative superiority resulting from technological leadership.[2]

Recognition of the centrality of these technological disparities has naturally led to efforts to diminish, close, or even reverse them. The process of technological development in such "follower" countries can, in a broad sense, be attributed to a combination of the mobilization of internally accessible resources and the transfer of technology from external sources. The precise nature of the link between these aspects of technological development varies according to country, sector, and specific technology. For example, Japan has been very successful in absorbing foreign technology and building on that base through the efficient allocation of internal resources.[3, 4] Other countries are widely considered to have difficulties absorbing transferred technology to a level of product quality comparable to that of the source country.[5] While this is generally true for non-industrialized states, it is also apparently the case for some countries as relatively developed as the USSR.

The importance of technology transfer to the economic and military capabilities of the USSR has led to a major policy debate in the US. Since the Cold War, the US has attempted to restrict the export of critical technologies to the Soviet Union. Export control laws were established and licenses required in these areas. In addition, the US pursuaded its NATO allies and Japan to participate in this effort. An informal group known as the Consultative Group Coordinating Committee (COCOM) was created to provide a forum in which uniform policies for technology transfer could be developed.[6] In the past decade, however, these structures have been subject to attack from a variety of perspectives. For some, the policies were becoming increasingly porous, allowing the USSR to obtain foreign technology through a variety of "unplugged leaks".[7] On the other hand, those with an interest in the Soviet market have argued that such restrictions are of little significance in the wake of growing Soviet technological progress, and simply deprive the firms of business. Some political analysts have also argued that the free-flow of technology creates an interdependent relationship which limits conflict and forces the USSR to "think twice" before undertaking political initiatives which might interrupt the flow of this technology. According to this view, limits on technolgy transfer will merely encourage the USSR to develop their own capabilities in these areas.[8]

These criticisms have led to a number of new studies and efforts to assess US policy in this area, and have resulted in a variety of policy prescriptions aimed at minimizing the transfer of "sensitive" technology to the USSR. The prescriptions range from a broad prohibition on the transfer of products, processes, or know how to specific efforts to identify the most sensitive and unavailable technologies on which to focus.[9]

The wide variation of perspectives and policy prescriptions can be attributed, in large part, to the general lack of understanding of the links between indigenous technological development and technology transfer. Most of the evaluations of this link are impressionistic, or at best, are based on a few well known case studies. Analysts speak of technological gaps in terms of years between the US and USSR levels of proficiency, or of the US as being "one or two generations ahead". Such assessments are ambiguous, at best, are generally highly impressionistic, and do not form a solid foundation for analysis and policy formation. To date, quantitative analyses of the rate of technological development and the role of technology transfer have been lacking. Such quantitative analyses, however, are would be useful in the development of a systematic and well grounded policy for technology transfer.

There has been a long standing recognition of the possible utility of a quantitative measure of transferred technology. An early attempt was made by G. Foster and N. Nissenoff, who used a technological index to "rank...the technology being transferred and that being practiced in the host country."[10] This approach has been regarded as fruitful by its authors but it does suffer from a number of severe limitations:

   (a) The index used by Foster and Nissenoff consists of a linear
       combination of six factors whose values are based entirely on the
       estimates of a panel of experts. They are combined without weighting.

   (b) There is no time evolution built into Foster and Nissenoff's
       algorithm. It is not useful in forecasting changes in the ability of
       a specific country to absorb transferred technology.

Other work on the quantitative aspects of technological development has been focused on the dynamics of technological substitution. This work,

however, is not directly applicable to the analysis of technology transfer. This contribution has recently been reviewed Linstone and Sahal [11]

A recent work by M.N. Sharif and K.M.A. Haq presents a model for technology transfer in terms of spacial diffusion and the potential for technology transfer between countries.[12] They use classical material diffusion formalism to describe the diffusion of technology. They also equate differences in technological levels with the diffusion driving potential. While interesting, this analogy between the process of technology transfer and classical diffusion is not demonstrated in a convincing manner. Sharif and Haq demonstrate their approach with an example related to the diffusion of computer technology. To measure the degree of assimilation of computer technology in a given country they use the total installed computer memory in this country. This parameter is problematic in our view because: (a) It is extensive (dependent on the size of the system, like volume), while we regard technology as an intensive variable, (independent of system size, as in the case of temperature); (b) It does not reflect modern computer architecture, in which other factors such as operating speed and time sharing are of great significance.

In this paper, we shall present a semi-empirical, quantitative model of technological "catch-up" which relates the behaviors of the technological leader and followers. The behavior of the follower nation(s) is described by differential equations which relate the rates of progress of leaders and followers to their present levels of achievement and to the technological gap between them. These coupled equations are solved to yield a generalized analytic solution for the level of proficiency of the follower as a function

of time in terms of some initial levels of technology for the leader and follower, and constants describing the indigenous rates of development for both and the rate of technology transfer between them.

While this model incorporates a number of simplifying assumptions that are discussed below, it can be used as a first approximation to describe the behavior of leaders and followers and to assess the rate constants. We begin this assessment by exploring various classes of behavior which apply to different situations and distinct relationships between the indigenous rate constants and the rate of technology transfer. On this basis, we illustrate the model through a comparison of the evolution of US and Soviet main-frame computers over 25 years and calculate the rate constants in this case. As will be demonstrated, the general model is found to be applicable to this case and is useful in analyzing the nature of the technological gap in this area.

II. Conceptual Development of the Model

As many studies have shown, technological development in general follows a logistic curve.[13] This curve, first proposed by the demographer Raymond Pearl in the 19th century, follows a trace best described by the letter "S". The logistic curve describes exponential growth, which is constrained by a limit over which it cannot grow. The limit may be physical like the speed of light, or may consist of economic or social constraints, as were apparent in the case of air transport and the SST. At the beginning, a logistic curve is essentially identical to an exponential curve. As the technology advances, however, the curve begins to deviate from the exponential. The extent to this deviation increases, and in the final stage, the curve assymptotically approaches the established limit for development. In other words, the

development of a given technology begins slowly and the curve is rather flat.(Fig. 1) After a short period of time, the level of proficiency increases more and more rapidly. In the third stage, the physical limits of the technology are neared, or the market is saturated, and the evolution slows again.

In analyzing technological development and transfer, there is usually a clear distinction between the technological "leaders" and the technological "followers".[14] For any particular technology, the leaders, by definition, are the first to develop and market the innovation and to make improvements in the technology.

The follower states, (or firms, in a domestic context), in turn, develop or otherwise acquire the same technology later than the leaders, often using concepts, personnel or components supplied by the leaders. Ideas and methods developed externally can provide the follower with a basic direction and "proof of concept" for internal development, and publications often provide details. Specific components and machinery imported from abroad can create the foundations for indigenous development, or can supply the few basic pieces in the process which are not internally available.

Perhaps most importantly, the physical movement of people provides a great deal of expertise. Students and trained professionals can gain "hands on experience" in foreign labs and enterprises and experts from the leader states and firms are often available to provide assistance.[15] These various contributions can come through legal channels or less orthodox paths, but the objective is the same. Regardless of the path and source, during the learning phase, each form of technology transfer is expected to aid development.

By definition, the technological followers start later or, as happens in many cases, their indigenous development capabilities are initially much more limited than that of the leader. Thus, the initial growth rates are slower. While external sources of technology may exist and be available, the follower usually lacks the infrastructure necessary to absorb and exploit this potential. There may be insufficient trained personnel to comprehend the available material, or essential resources or skills may be lacking. (For example, the blueprints for aircraft engine manufacture are widely available, but the necessary materials and skills to produce the parts are scarce.)

As the level of technological capability increases, however, the follower begins to "catch up" with the leader, and the gap between them may be reduced, (unless the leader has gone to a new technology and thus begun the process again). During this stage, technology transfer is likely to be of greatest importance. As the gap decreases, the role of technology transfer is again reduced. There is little to learn from external sources, and the rate of development is largely determined by the nature of the technology and the availability of indigenous resources.

In summary, then, the role of technology transfer for a follower country can be described in terms of three phases:

*The initial phase, in which development is slow compared to that of the leader and the absorptive capacity for technology transfer is too limited to allow a high rate of progress;

*The "learning" phase, in which the rate of development is much greater and depends both on the indigenous resources, the gap between leader and follower, and the rate of technology transfer;

*The third phase, in which the gap is reduced or closed and the role of technology transfer is again reduced. (In many cases, this phase is far out in the future. There are, however, some notable exceptions, as in the case of Japan, S. Korea, Israel, and other intensively innovating states.)

A Quantitative Formulation of the Model

In attempting to assess and analyze the role of technology transfer, a number of specific questions are in order. Perhaps the most important concern the degree to which technology transfer can assist the rate of development of the follower country in a specific technology. In most cases, for example, there is evidence that transferred technology contributes in a significant manner to the rate of development. When the technology is close to its pre-ordained limits and the leader relinquishes its efforts to innovate in this technology, the follower can close the gap, and even overtake the leader. (Case a, figure 2) In other cases, however, the potential to transfer the same technology has little impact on the rate of development. The gap between leader and follower increases despite technology transfer (Case b).

The purpose of this section is to develop a quantitative method for comparing the rates of development of the leader and follower, to allow for an evaluation of these and related issues.

As noted above, it is assumed that the leader develops in a manner independent of the follower. Technological proficiency may be measured by some quantity P. Use of P in a quantitative model would not be sensible, however, since any function of P might just as well have been used and would

change the model properties. We introduce a dimensionless measure x, that is, some function of P;

$$x = f(P) \qquad\qquad (1)$$

so that

$$dx_L/dt = k_L \qquad\qquad (2a)$$

or $\qquad x_L(t) = x_L^0 + k_L t \qquad\qquad (2b)$

for the leader. Thus, we are assuming that there is some measure of technology that increases linearly in time for a leading (or decoupled) country. The development of the follower must be measured in a similar form, though this will not, of necessity, imply a linear increase with time for X_F (technological know-how) of the follower. From equations 1 and 2, we can conclude that the simplest function representation of the connection between the measures X and P is

$$x = \ln P \qquad\qquad (2c)$$

This is consistent with emprical evidence that technological proficiency P evolves exponentially.*

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*This presentation of the problem does not incorporate the effects of physical limits to development. It is, thus, appropriate to apply it only at the first stages of growth.

The rate of technological progress of the follower consists of two contributions:

$$dx_F/dt = K_F + f_1(x_F)\, f_2(x_L, x_F) \qquad \text{Eq.3}$$

The first contribution, k_F, represents the indigenous development of the follower and the second contribution represents that of technology transfer. In many cases, k_F is significantly less than the second transfer term and progress is thus dependent on the gap between leader and follower. As the gap decreases, the contribution of technology transfer would logically become less significant, while for large gaps, the follower has a large reservoir from which to draw.

The functions $f_1(x_F)$ and $f_2(x_L, x_F)$ are generalized functions implying a dependence of the follower's rate of progress on his technological proficiency in the field and on the gap between him and the leader. In this case, the simplest form is

$$f_2(x_L, x_F) = (x_L - x_F) \qquad \text{Eq.4}$$

We choose $f_1(x_F)$ to be a dual-valued function, such that for small x_F, it is zero, but when x_F has crossed a particular threshhold, it is a constant, k_T. For example, an indusrialized state such as Japan is able to pursue a given technology once a decision has been made to do so, but a less industrialized state may not have the capability even to absorb available technology. Until this capability is developed, the value of the function f_1 is zero.

This functional form of $f_1(x_F)$ is consistent with empirical experience. For countries with little technological development of their own, there is almost nothing they can absorb in the form of technology

transfer. Once they have gained a minimal amount of knowledge, (the threshhold point), however, they can begin to absorb this externally developed component.

Now we can solve Eq. 2-4 for x_F as follows:

$$dx_F/dt = k_F + k_T(x_L-x_F) \qquad \text{Eq.5}$$

$$dx_F/dt + k_Tx_F = k_F + k_Tx_L \qquad \text{Eq.6}$$

We know that $x_L=x_L^0 + k_Lt$ from Eq. 2c and plugging this in, we find that:

$$dx_F/dt + k_Tx_F = k_F + k_Tx_L^0 + k_Tk_Lt \qquad \text{Eq.7}$$

This is an inhomogenous linear differential equation. The general solution to the entire equation consists of a general solution x^H to the homogenous equation (righthand side equals zero) plus any particular solution x^P to the entire, nonhomogenous equation. Thus,

$$x_F = x^P + x^H \qquad \text{Eq.8}$$

The solution to the homogenous equation is:

$$x^H = Ce^{-k_Tt}$$

where C is a constant of integration. We can also assume that a particular solution will have the same form as the solution for the leader. Thus,

$$x_P = A + Bt \qquad \text{Eq.9}$$

Plugging this into Eq. 2-8, we find that

$$B + k_TA + k_TBt = k_F + k_Tx_L^0 + k_Tk_Lt \qquad \text{Eq.10}$$

Matching constant and first-order terms in time, we find:

$$B = k_L \qquad\qquad\qquad\qquad\qquad\qquad\qquad\text{Eq.11}$$

$$A = (k_F - k_L)/k_T + x_L^0 \qquad\qquad\qquad\qquad\text{Eq.12}$$

Thus, the development of the follower as a function of time is:

$$x_F(t) = (k_F - k_L)/k_T + x_L^0 + k_L t + C e^{-k_T t}. \qquad\qquad\text{Eq.13}$$

To solve for the constant of integration, C we use an initial condition. At t=0:

$$x_F(0) = x_F^0 \text{ and } C = x_F^0 - x_L^0 - (k_F - k_L)/k_T \qquad\qquad\text{Eq.14}$$

Finally, this yields the following analytic solution:

$$x_F(t) = x_L^0 + k_L t - (k_L - k_F)/K_T$$
$$\qquad - [(x_{L}0 - x_F0) - (k_L - k_F)/k_T] \; e^{-k_T t} \qquad\qquad\text{Eq.15}$$
$$\quad\text{(initial gap)} \qquad\qquad \text{(final gap)}$$

The form of this solution reminds one of other cases of coupled dynamic behavoir. The first line of the solution represents the "steady state" solution, for large t, and the second line is the transient solution, which may be important for smaller time spans. In considering the steady-state portion, we note that the first two terms,
$x_L^0 + k_L t$ represent the progress of the leader, $x_L(t)$. The remaining term, $(k_F - k_L)/k_T$ represents the "steady state" gap between leader and follower. It is important to note that the gap does not necessarily vanish for large t. This conforms with observed behavior and is consistent with the assumption that the leader maintains a constant effort to develop new technology, as represented in Eq.1. The gap

$$G = x_L - x_F \qquad\qquad\qquad\qquad\qquad\text{Eq.16}$$
$$= (k_L - k_F)/k_T + [(x_L^0 - x_F^0) - (k_L - k_F)/k_T] e^{-k_T t}$$
$$\quad\text{final gap} \qquad\qquad\qquad\qquad \text{transient}$$

When the initial levels are equal, as is frequently the case, the "steady state" solution for large t is

$$G_{infinity} = (k_L - k_F)/k_T \qquad \text{Eq.17}$$

In brief, we assume a measure of technology proficiency X so that for the leader

$$dx_L/dt = k_L \qquad \text{Eq.18}$$

and for the follower

$$dx_F/dt = k_F + k_T(x_L - x_F) \qquad \text{Eq.19}$$

The constants K_L and K_F measure the two countries' intrinsic learning rates and K_T the transfer coefficient. These equations have the solution

$$x_L(t) = x_L^0 + k_L t \qquad \text{Eq.20}$$

$$x_F(t) = x_L(t) - G_{inf.} - (G_0 - G_{inf.})e^{-k_T t} \qquad \text{Eq.21}$$

where $G_0 = x_L^0 - x_F^0$ (the initial gap)

and $G_{inf.} = (k_L - k_F)/k_T$ (the eventual gap)

Discussion

Prior to the analysis of a single case, it is useful to examine the application of this model in a series of general cases. Different forms of generalized behavior can be illustrated by examining the relative rates of technological development which are associated with varying values of K_L, K_F and K_T. (The reader should note that K_L, K_F and K_T are in units of years^{-1}. In Figure 3, we compare the effects of K_L and K_F on the technological gap assuming that the initial gap is zero. One can distinguish between two general cases; when the indigenous rates of development of leader and follower are relatively similar ($K_L = K_F$) and when the leader's development is much greater than than of the follower ($K_L \gg K_F$). (A third case, in which the follower's rate is greater than that of the leader, is possible, but in this case, the follower would eventually become the leader and is thus included in the first case. A more detailed analysis of this third case will be presented in a subsequent paper.)

In cases where the indigenous rates of development are similar, so that the rate of the leader is only marginally greater than that of the follower, the asymptotic level of the gap is relatively small.

In contrast, when the indigenous rate of development of the follower is significantly smaller than that of the leader, the gap grows much more rapidly at the beginning and the "steady state" gap is far larger than that in the previous case. For example, for a fixed k_T (rate of transfer) and a given $k_L = .5$ yr^{-1}, values of $K_F = .4$ yr^{-1} and $k_F = .2$ yr^{-1} yield very different size gaps. For the lower level of indigenous development, the gap opens quickly and reaches a level which

is over a factor of 2.5 greater than that for $K_F = .4 \text{ yr}^{-1}$ in 25 years. For large times, that gap exceeds a factor of 3.

This distinction may be useful in constrasting the behavior of the advanced industrial states, such as Japan, with the behavior of states with a smaller indigenous technological capability, such as the USSR. In the former case, the gap rapidly reaches its asymptotic value, which isrelatively small. (A more complex version of this model, which would include the tendency of the leader to diminish his effort and for technology to reach a maturity embodied in physical limits, would demonstrate technological catch-up in this case.) For the case of a small k_F, the gap is relatively larger and takes longer to reach a steady state.

The rate through which the technological gap changes is very sensitive to the value of K_T, the rate constant for technology transfer. For a given k_L and k_F, different values of k_T result in various types of behavior (Figure 3). For a relatively high value of k_T the gap reaches a fixed and relatively low level in a short period of time. For $k_L = .5 \text{ yr}^{-1}$, $k_F = .2 \text{ yr}^{-1}$, as in the case of US and Soviet computer development discussed below, the gap reaches about two thirds of its "steady state" value in six years when $k_T = .2$ yr^{-1}. When $k_T = .06$, this value is not reached until 20 years have passed, and the "steady state" gap is over 3 times as great as when $k_T = .2 \text{ yr}^{-1}$. For a $k_T = .02$ the "steady state" gap is 10 times greater than for $k_T = .2 \text{ yr}^{-1}$. In other words, the relative rate of technology transfer, as measured in k_T, has a major effect on the gap, as is apparent in eq. 2-17.

Example: An Analysis of Soviet Computer Development

In order to illustrate the value of the algorithm discussed above in assessing technological development, we have chosen to analyze the development of main frame computers in the USSR. This example is of particular importance as the issues of electronics and computers are central to many of the analysis and policy debates concerning East-West technology transfer. Opponents of such transfers note that any addition to Soviet equipment or knowledge, no matter how obsolete in terms of the U.S., will be exploited by the Soviet military.[16] Much of the debate hinges on the relative rates of progress of computer development, and is thus an example of the type of issue which appears amenable to the quantitative analysis proposed in this study.

In analyzing the development of digital computer technology in the USSR relative to that of the US, we are also taking advantage of the fact that the USSR has chosen a "follower" strategy. As Goodman[17] and others [18] have pointed out, the Soviet Union began research and development in this area at the same time as the US, and in the early 1950s, had a very similar capability. During the next two decades, a significant gap grew as indigenous development proceeded very slowly in the USSR while the US digital computer industry developed very rapidly in response to commercial as well as military demand.

By 1967, however, the result of continued indigenous effort and transferred technology were beginning to become apparent. Emphasis was placed on the emulation of proven US designs and products. In particular, since that time, Soviet computers have been closely modelled upon IBM main frame systems. The Ryad I and II follow the IBM 360 and

370 series very closely, and the rate at which the gap had been increasing began to decline. Thus, the leader-follower model on which we have the quantitative approach presented above should be useful in analyzing this case.

Results

A full analysis of comparative computer development in the US and USSR is beyond the scope of this study. In the first place, comparasion depends on the definition of figures of merit through which relative performance can be assessed. In anything as complex as a main-frame computer, such assessment may require analysis of components, architecture, input/output systems, and software. In addition, the application of the system is of importance. For example, for the solution of coupled differential equations central to the design of nuclear weapons, the speed of floating-point operations are critical. For cryptography, rapid manipulation of data is central, and a computer which is optimized for the former is unlikely to also be optimized for the latter task. A very important descriptive effort comparing US and Soviet computers in great detail has been undertaken by Goodman, et al.[19]

In order to illustrate the model, we have chosen a single parameter P by which to compare US and Soviet computer development. Our choice is the number of operations per second (ops) of which a given computer is capable. (Other measures, such as the power/delay factor, mean-time between failuires (MTBF), or cost per instruction, were considered, but data for these factors in both the US and USSR was not readily

available. In addition, the ops measure is similar to the "processing data rate" (PDR) used by the US government and the COCOM countries to compare computer capabilities. Thus, this figure of merit provides data is relatively parallel to that used in the context of debates over the transfer of computer technolgy to the USSR.)[20]

For the US, the rate of development displays, an exponential growth pattern for P. Thus, using X = ln P we will satisfy our linear growth requirement for X. According to the data collected by Knight[21] and presented in Figure 4, between 1952 and 1975, the number of operations per second of main-frame computers in the US grew by a surprisingly constant factor of approximately 1.6 per year.

In the USSR, computer development can be traced between 1955 and 1980 through the Ural, Besm, Ryad I and Ryad II series. In examining the number of operations per second in these systems as a function of time, we see a changing trend (Figure 4). Between 1955 and the mid-1960's, the growth curve was relatively flat. In the late 1960's, however, the rate accelerated.

Despite the relatively crude measure of development which we have selected, the development of Soviet computer technology as measured by the growth in the number of operations of per second, follows the model presented above remarkably closely. The "leader-follower" behavior is quite apparent, and as expected, the initial rate of development of the USSR, as measured by the value of the rate constant K_F, is less than half that of the US. For the U.S., we have calculated a K_L of .5 yr^{-1}, while for the USSR, K_F = .2 yr^{-1}. This relatively small value of k_F reflects a limited Soviet indigenous capability in this

area, and a relatively undeveloped technological base and infrastructure which produced the BESM and URAL series of computers.

In the process of accruing knowledge and gaining access to external technology, the capabilty has grown rapidly. The development curve is much steeper than was apparent during the earlier phase, when transferred technology played a significantly lesser role. For this case, we calculate by curve fitting a value of $K_T = .06 \ yr^{-1}$ for the constant describing the rate of technology transfer.

Summary and Conclusions

In this paper, we have presented a particular quantitative model of technology transfer and the relationship between leader and follower, and we have demonstrated that this particular approach is useful in describing observed behavior in this important area. The brief analysis of the comparative development of Soviet and US computer development, and Figure 4 in particular, serve to demonstrate the validity of the quantitative approach presented above.

A complete exploration of the insights provided by the model will require detailed analyses in a variety of cases involving different technologies and different countries. However, some preliminary implications are suggested in the case of US and Soviet computer development which we have examined. In particular, we observe that the behavior of the USSR is consistent with that of a technological follower. We also note that the indigenous capability is limited but significant in the area of computer development.

At the same time, we note that the gap could also potentially be

increased if the US were to increase its own rate of innovation in this area (i.e., increase K_L). Accelerating the appearance of new generations of technology, such as VHSIC (very high speed integrated circuits) could potentially contibute to this objective. While the complete embargo of such technology is very costly and difficult to achieve, this approach raises the cost of "catch-up" for the follower and allows the leader to increase the size of the gap.

This problem and the broader questions of policy prescription also serve to indicate some of the limitations of the model we have presented. As noted above, we do not specifically include the third stage of technological development in which the technology has matured and the physical or market-based barriers become dominant. In the computer area as a whole, this stage has apparently not yet been reached, but in the sub-area of VLSI, for example, there are indications of physical limits which prevent continuous growth. The importance of these limits await investigation in further quantitative analyses of the problem of technological development and transfer.

Acknowledgements

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Figure Captions

Fig. 1: Stages in the development of technological proficiency.

Fig. 2: Comparison of the development of technological proficiency of a leader with two types of followers. Case (a): A follower with high indigenous learning capability. Case (b): A follower with a relatively low indigenous learning capability.

Fig. 3: Relative effects of the different rate constants on the dynamics of the technological gap and on the steady state value.

Fig. 4: Development of computer main frames in the US[21] and in the USSR[17-19] (In thousands of operations/sec. vs. time)
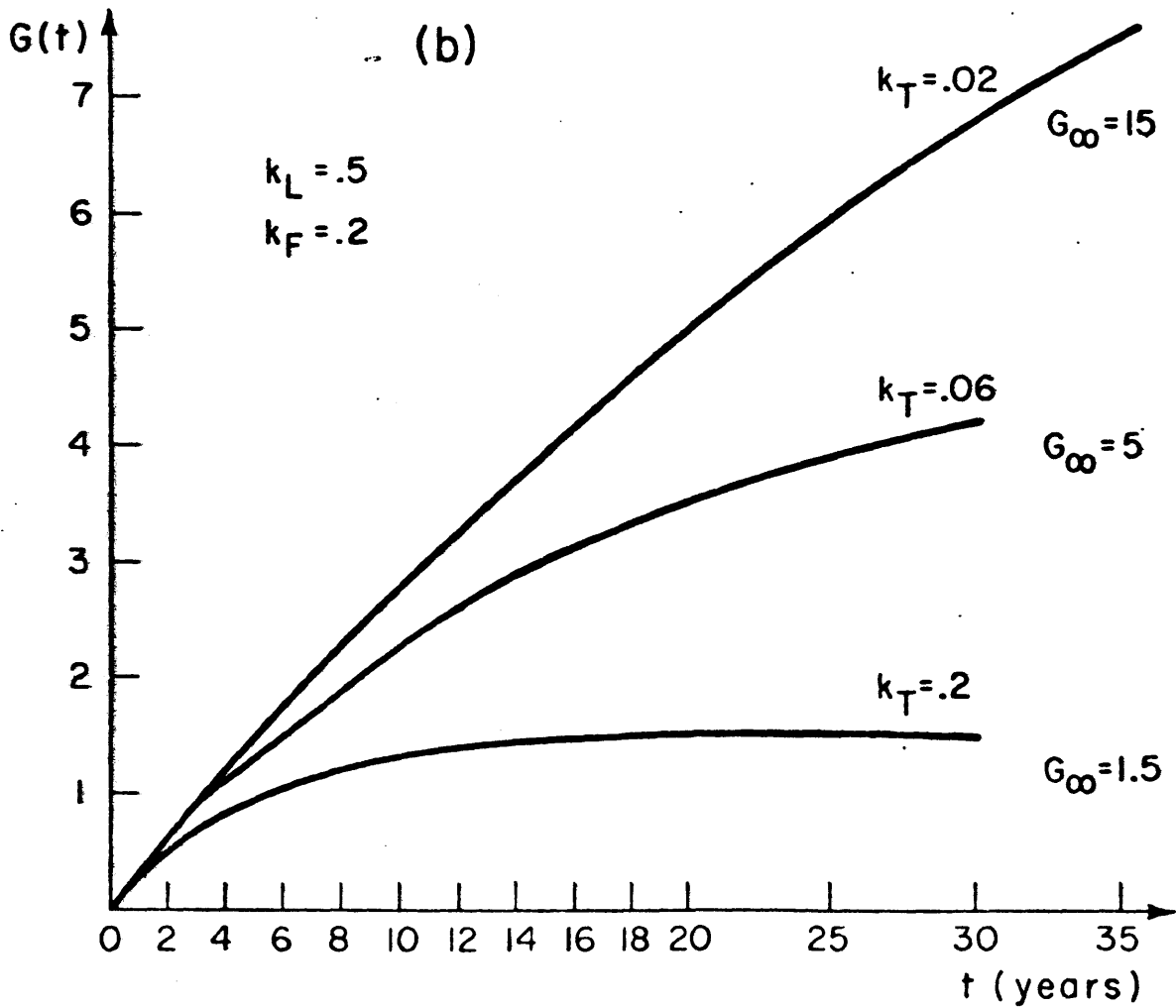
Level of
Technological
Proficiency

STAGE
III

STAGE
II

STAGE
I

time

Fig. 1

Fig. 2

Fig. 3

Fig. 4